Assessment of the science behind the NSW Government's sea level rise planning benchmarks

NSW Chief Scientist and Engineer

April 2012

NSW
GOVERNMENT
Chief Scientist
& Engineer

The Hon Robyn Parker MP
Minister for the Environment
Minister for Heritage
Chair, Coastal Ministerial Taskforce

Dear Minister

Report on the science behind sea level rise benchmarks

In February this year, as Chair of the Coastal Ministerial Taskforce, you requested I prepare a report on the adequacy of the science informing the NSW sea level rise benchmarks. This work has now been completed and I am sending this report to you for your consideration.

In considering the science behind sea level rise benchmarks, the one constant that emerges is change. The way the science has been used to determine benchmarks is adequate, given the current level of knowledge. However, for some years to come there will be more and better models for predicting sea level rise which will be informed by more and better data enabled by rapid advances in sensing, positioning, computational and imaging technologies.

We are fortunate in NSW, and Australia more broadly, to be able to draw on considerable expertise in fields relevant to sea level rise projections, monitoring, and planning, with several centres of expertise within local universities and other research organisations. This will enable interpretation and adaptation of global models to build much more precise local models specific to various NSW coastal locations.

Many people have been generous in providing their time and advice during the preparation of this report. I would like to thank Dr Chris Armstrong and Dr Jaclyn Aldenhoven in my office, Dr John Church (CSIRO), Dr Kathleen McInnes (CSIRO), Professor Matthew England (UNSW), Dr Shayne McGregor (UNSW) and Mr Steven Jacoby (Queensland Department of Environment and Resource Management), and the Coastal Interagency Working Group, particularly officers from the Office of Environment and Heritage, Department of Premier and Cabinet, and Department of Planning and Infrastructure.

Yours sincerely

Mary O'Kane
NSW Chief Scientist and Engineer

Acronyms

A1	IPCC Special Report Emission Scenario A1 (Appendix 1)
A1B	IPCC Special Report Emission Scenario A1B (Appendix 1)
A1FI	IPCC Special Report Emission Scenario A1FI (Appendix 1)
A1T	IPCC Special Report Emission Scenario A1T (Appendix 1)
A2	IPCC Special Report Emission Scenario A2 (Appendix 1)
AOGCM	Atmosphere-Ocean General Circulation Model
AR4	IPCC Fourth Assessment Report
AR5	IPCC Fifth Assessment Report
ARC	Australian Research Council
B1	IPCC Special Report Emission Scenario B1 (Appendix 1)
B2	IPCC Special Report Emission Scenario B2 (Appendix 1)
BOM	Bureau of Meteorology
CGSE	ARC Centre of Excellence for Geotechnical Science and Engineering
COE	Centre of Excellence
CMIP3	Phase 3 of the Coupled Model Intercomparison Project
CMIP5	Phase 5 of the Coupled Model Intercomparison Project
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
FAR	IPCC First Assessment Report
ICSU	International Council for Science
ICT	Information and Communication Technologies
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
NICTA	National ICT Australia
OEH	NSW Office of Environment and Heritage (Department of Premier and Cabinet)
SAR	IPCC Second Assessment Report
SRES	IPCC Special Report Emission Scenarios
TAR	IPCC Third Assessment Report
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
USACE	United States Army Corps of Engineers
WCRP	World Climate Research Programme
WGCM	Working Group on Coupled Modelling
WG I	IPCC Working Group 1
WMO	World Meteorological Organisation

Executive Summary and Recommendations

Sea level is influenced by a number of meteorological and other physical factors that can affect the mass or volume of the water in the oceans including from melting ice and thermal expansion due to changes in sea temperature. The nature and relative impact of sea level change is the subject of much research around the world with coordinated efforts to bring the science together and model the systematic impact over time. Building our ability to predict sea level changes has an important role to play in assisting societies to respond to sea level rise into the future. The modelling involved in understanding sea level rise also has the benefit of giving us a more detailed handle on the likely impacts of other local coast phenomena such as storm surges.

Sea level change has been a constant characteristic of earth systems. 20,000 years ago oceans were estimated to be 140m below current levels, and 100,000 years before that, the level of the sea is estimated at 4-6m above today's level.

Global sea level rise is caused by two major factors: thermal expansion of the oceans (water expands as it warms) and the loss of land-based ice due to increasing melting and subsequent water flow into oceans. Estimates of global sea level rise in the late 19th century to early 21st century, measured through tide gauges and more recent (since 1993) satellite altimetry, show a rise of between 1.7mm/year to over 3mm/year.

In 2009 the then NSW Government developed two benchmarks - for 2050 and 2100 sea level rise. Overall, the approach was one whereby projections for global sea levels at the middle and end of the 21st century were added to other more regional estimates for these time periods, as well as a global accelerated ice melt factor. This methodology is similar to that used in other jurisdictions in Australia and around the world, with some international jurisdictions utilising more extreme climate modelling approaches to explore possible worst case scenarios.

The development of the NSW benchmarks drew on international modelling collaborations. These models are part of a global Coupled Model Intercomparison Project (CMIP) initiative to coordinate climate modelling by the World Climate Research Programme (WCRP) (sponsored by the United Nations Educational, Scientific and Cultural Organisation (UNESCO), the World Meteorological Organisation (WMO) and the Intergovernmental Oceanographic Commission (IOC)) which sees the release of a new set of climate model predictions approximately every six years, making use of new and updated models that have emerged over these periods.

The climate models are available to the public for use and analysis; however the scale, complexity and quantity of data produced requires considerable expertise to use and analyse the outputs. The climate models produce outputs on the global scale, but also on the regional scale, meaning that with the availability of appropriate expertise, they are a valuable resource for developing understanding for NSW regional and local sea level change into the future.

Improved models and cheaper and more advanced sensing, positioning, computational and imaging technologies are constantly being developed. These technologies will produce better data and a clearer picture of changes in climate and sea level now and into the future. These technologies will enable a better regional and local understanding of climate change.

The development of sea level projections at the regional level requires the synthesis of data emerging from various sources, and would benefit from testing and review by experts in relevant fields. Accessing such expertise would assist in assessing sea level projections in the light of local conditions including geomorphology, infrastructure and weather.

New South Wales is fortunate to have access to considerable expertise in relevant fields for climate projection and infrastructure planning, including in organisations such as the Australian Research Council (ARC) Centre of Excellence (COE) for Geotechnical Science and Engineering headquartered at the University of Newcastle, ARC COE for Climate System Science headquartered at the University of NSW, the SMART Infrastructure Facility at the University of Wollongong, the CSIRO, National ICT Australia (NICTA) headquartered in Redfern, the Water Research Laboratory at the University of New South Wales and the Bureau of Meteorology(BOM). Bringing appropriate experts together in a structured way to review projections, analyse new models, and support communications initiatives will be an important step in improving the approach so that it is understood by councils and the greater community.

This expertise could be brought together through a Technical Advice Centre to support local councils in interpreting and translating scientific findings into practice in infrastructure planning and risk management related to sea level rise and extreme events. The Technical Advice Centre ideally could be located at the headquarters of the Australian Research Council Centre of Excellence in Geotechnical Science and Engineering (CGSE), headquartered at the University of Newcastle but involving as core partners the Universities of Newcastle, Wollongong and Western Australia. It was one of only 13 ARC Centres of Excellence awarded nationally in the most recent competitive round (2011). The ARC Centres of Excellences are the most prestigious research centres in Australia through which high-quality researchers maintain and develop Australia's international standing. They are selected through a highly competitive and open process that is independent of research field.

The CGSE’s focus on geotechnical engineering makes it an ideal organisation to translate the scientific findings into engineering solutions for local councils in infrastructure planning on coastal locations including for future sea level rise and extreme events. The CGSE already has considerable experience in working with organisations developing coastal infrastructure such as roads in a wide variety of conditions including sand dunes and areas affected by soil erosion. The CGSE would coordinate and collaborate with other centres of expertise in Australia as mentioned above, ensuring that councils receive the best and most up-to-date information and advice. A further advantage of the Technical Advice Centre being headquartered in Newcastle is its location in the Hunter region which is close to the central and north coasts of NSW, which have been identified as locations of particular focus in dealing with rising sea levels and inundations.

Many jurisdictions around the country and the world are also dealing with issues related to projecting and adapting to sea level and climate. Maintaining a close watching brief over how other countries and states measure, calculate and use projections will be important for NSW into the future.

A major barrier to efficient implementation of planning changes consequent on revised sea level projections relates to the ability to communicate the complexities of the issues in a form that is accessible to a broad audience. In particular communication of the likelihood of frequent revisions and refinements as more data becomes available and models improve, is vital. The broad audience for this communication includes local councils that need to implement policies and local communities and the general public who have to live with the impact of changed policies. The issues are highly complex, the debate among scientists is confusing and, given the long term nature of various aspects of sea level rise, it is difficult for people to appreciate the logic of early action and adaptation.

The way the science has been used to date to determine benchmarks for sea level rise in NSW is adequate, in light of the evolving understanding of the complex issues surrounding future sea levels. Accordingly, the report recommends the following:

Recommendation 1 (Projections and review)

a. Given the expected ongoing release of new and updated sets of global climate models and projections, work should begin on establishing the appropriate framework for deriving updated sea level projections for NSW coastal locations and then refining these projections as yet further model outputs become available.

b. Considering the rapid pace of advancement in scientific understanding and computational and modelling capacity, and the improvement and lower costs of sensors, the NSW sea level rise projections should be reviewed at frequent intervals including at such time as the release of major new data for future climate projections.

c. Sea level rise projections for the NSW coast should be reviewed through a process of formal consultations with experts in fields including climate science, geotechnical engineering, oceanography, atmospheric science, mathematical modelling, statistics, computational science and computer engineering.

Recommendation 2 (Regional focus)

The NSW Government could look toward more regionally specific calculations that take into account specific sea level, topography, flood risk and other conditions along the NSW coast. This would allow factors such as probability of extreme events (e.g. severe storms and surges) and impacts to be incorporated into local planning.

Recommendation 3 (Technical Advice Centre)

The NSW Government should explore the feasibility of establishing a Technical Advice Centre to provide support to local councils in interpreting and translating new scientific findings, and assisting councils in developing strategies, infrastructure planning, and appropriate risk management activities related to sea level rise and its associated impacts. Ideally this centre would be located within an appropriate centre of expertise in NSW, such as the Australian Research Council Centre of Excellence for Geotechnical Science and Engineering headquartered at the University of Newcastle. This centre should draw on other appropriate centres of expertise. The Technical Advice Centre could also coordinate the projection review activities in Recommendation 1.

Recommendation 4 (Communication)
The science behind sea level rise and future projections, as well as potential local impacts needs to be explained and available in plain English to local councils and members of the public. Communication material should be updated regularly, as this is a field where new data and new and updated models are constantly emerging. This information should be provided as supporting documentation to the NSW Government sea level rise polices, including s149 advice, Technical Notes and other material.

Contents

1. Introduction

NSW Government has established a Ministerial Taskforce to review the coastal planning policy in relation to sea level rise, with the following terms of reference:

(a) Review the operation of the Coastal Protection and Other Legislation Amendment Act 2010 including possible legislative amendments;
(b) Review the application of the sea level rise planning benchmarks and the adequacy of the science informing the benchmarks; and
(c) Propose future options to improve coastal erosion policy that do not increase liability or cost for the Government

The NSW Chief Scientist and Engineer was asked to investigate the adequacy of the science informing the sea level rise planning benchmarks as in the *NSW Sea Level Rise Policy Statement*.

1.1. Sea Level Rise Planning in NSW

The NSW State Government has jurisdiction over coastal planning, as recognised in the *NSW Coastal Policy 1997*, however local councils have primary responsibility for the regulation of planning and development in the coastal zone.

In 2009 the NSW Department of Environment, Climate Change and Water (now Office of Environment and Heritage (OEH)) developed the *NSW Sea Level Rise Policy Statement* that specifies sea level rise planning benchmarks. This policy sets out the NSW Government's approach to sea level rise, the risks to property owners from coastal processes, and assistance that Government provides to councils to reduce the risk of coastal hazards. The policy includes sea level planning benchmarks that represent an increase on 1990 sea levels of 40cm by 2050 and 90cm by 2100. The derivation of these benchmarks is set out in the *Technical Note: Derivation of the NSW Government's sea level rise planning benchmarks* (Department Environment, Climate Change and Water NSW, 2009). The benchmarks were developed to support consistent consideration of sea level rise in land-use planning and coastal investment decision-making.

Further to the Policy Statement, OEH released guidelines on incorporating sea level rise risk into flood risk (*Flood Risk Management Guide: Incorporating sea level rise benchmarks in flood risk assessments 2010*) and coastal hazard assessment (*Coastal Risk Management Guide: Incorporating sea level rise benchmarks in coastal risk assessments 2010*). These guides were developed to assist local councils, the development industry and consultants to incorporate the sea level rise benchmarks in coastal hazard and flood risk assessments.

The NSW Department of Planning in 2010 released the *NSW Coastal Planning Guideline: Adapting to Sea Level Rise* for incorporating sea level rise in land-use planning and development. The guideline was developed for all land fronting tidal waters including coastline, beaches, coastal lakes, bays and estuaries, and tidal sections of coastal rivers, as well as other low lying land surrounding these areas that maybe subject to coastal processes as a consequence of sea level rise. The guideline adopts a risk-based approach to planning and development assessment in coastal areas.

2. Overview of science behind sea level rise and benchmarks

Global sea levels have changed considerably over previous periods in the earth's history, for instance sea level approximately 20,000 years ago, at the time of the last glacial maximum, is estimated to have been 140m below current levels (Figure 1). Glacial melting between 20,000 and 6000 years ago resulted in sea level rise rates in ranges of 1m per century up to a rate of 4m per century (CSIRO, http://www.cmar.csiro.au/sealevel/index.html). Sea levels have been estimated to have reached heights up to 4 to 6m (or more) above present day sea levels during the last interglacial period, about 120,000 years ago (CSIRO, http://www.cmar.csiro.au/sealevel/index.html).

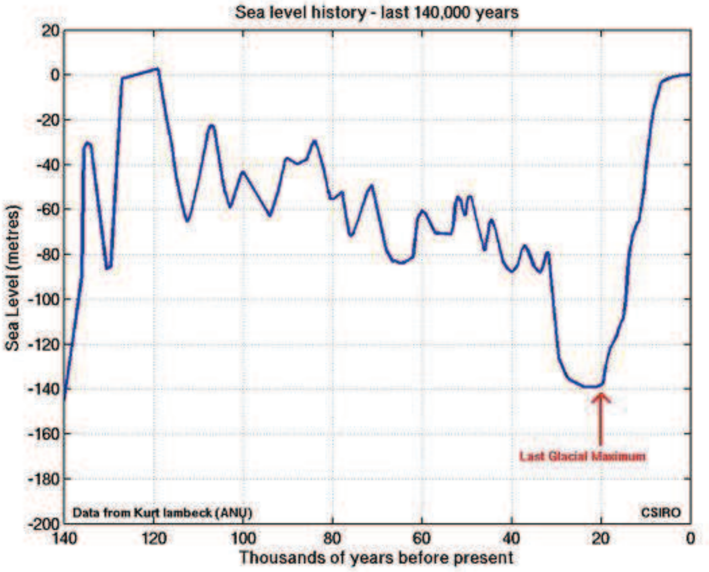

Figure 1: Figure reproduced from CSIRO Website developed from data from Professor Kurt Lambeck at ANU, illustrating Sea Level over the last 140,000 years (CSIRO, http://www.cmar.csiro.au/sealevel/index.html)

Coastal sediment cores and other paleontological sea-level data, tide gauge data records (beginning early 1800s), reconstructions of 20th century sea levels and satellite altimetry data indicate that the rate of sea level rise has increased from a few tenths of a millimetre per year over the previous millennium to about 1.7mm/year during the 20th century and to over 3 mm/year since 1993 when satellite altimetry technology first became available (Figure 2) (Church, Aarup, Woodworth, Wilson, Nicholls, Rayner, Lambeck, Mitchum, Steffan, Cazenave, Blewitt, Mitovica, and Lowe, 2010).

Measurements of present-day sea level change rely on two different techniques: tide gauges and satellite altimetry. Tide gauges provide a measure of sea level variation with respect to the land on which they lie or relative sea level. Since 1993 satellite altimetry has been used to provide a measure of sea level change or absolute sea level.

2.1. What causes sea level rise

Two major factors contributing to global sea level rise are thermal expansion of the oceans (water expands as it warms) and the loss of land-based ice due to increased melting (IPCC AR4 WG1, 2007). Due to the large thermal inertia of the ocean, it takes many decades for sea levels to adjust to the heat absorbed from the atmosphere. This means that even if warming stopped today, the sea levels would continue to rise for many decades (Victorian Department of Sustainability and Environment, 2011). The ability to predict the thermal expansion of oceans due to heat is much easier than estimating rise caused by melting land-based ice sheets such as those in Antarctica (Victorian Department of Sustainability and Environment, 2011).

Sea level is not rising uniformly around the world (IPCC AR4 WG1, 2007; CSIRO, http://www.cmar.csiro.au/sealevel/index.html). As discussed in the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4), sea level change in the future will not be geographically uniform, with regional sea level change varying within about ±0.15 m of the mean in a typical sea level rise projection (IPCC AR4 WG1, 2007). Understanding the regional distribution of sea level rise is important because regional or local sea level change and local weather events can impact society and the environment.

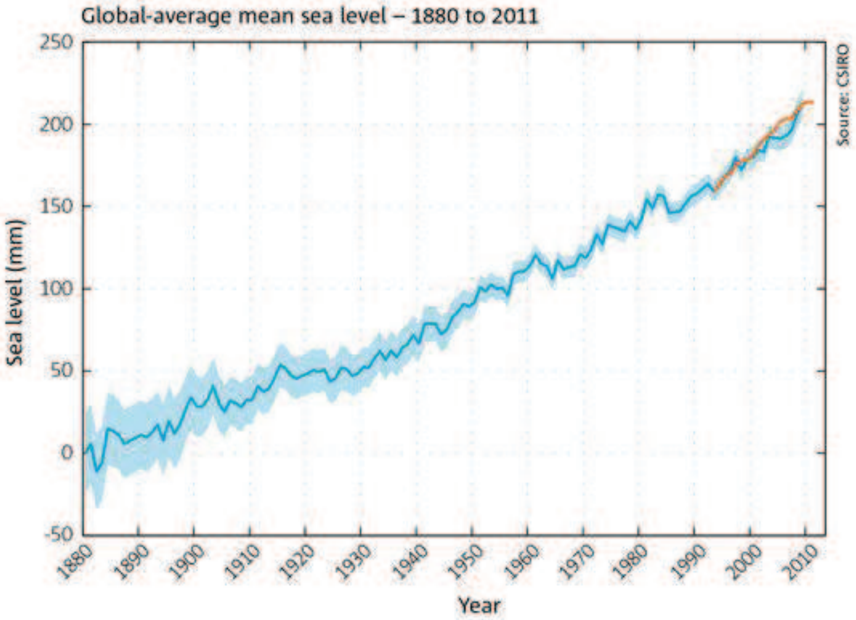

Figure 2: High-quality global sea-level measurements have been available from satellite altimetry since the start of 1993 (red line), in addition to the longer-term records from tide gauges (blue line, with shading providing an indication of the accuracy of the estimate) Reproduced from: (CSIRO and the Australian Bureau of Meterology, 2012)

2.2. Intergovernmental Panel on Climate Change

The Intergovernmental Panel on Climate Change (IPCC) is an international body established by the United Nations Environment Programme (UNEP) and the World Meteorological Organisation (WMO) to provide a scientific assessment of the current state of knowledge of climate change and its potential environmental and socio-economic impacts. The main activity of the IPCC is to provide, in regular intervals, Assessment Reports of the state of knowledge on climate change. To date there have been four Assessment Reports released and the fifth Assessment Report is due to be released in 2014. The IPCC does not conduct new research; its mandate is to make policy relevant reviews and assessments of the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change.

2.3. Climate Change Modelling

The interactions of physical processes including oceanographic, atmospheric and geographic processes in respect to weather and climate are highly complex. The complexity of these processes over different regions of the planet and different time periods means that to gain an understanding of possible climate effects into the future, models need to be established, run under different possible scenarios, tested against their ability to replicate current or past situations and then brought together. A spectrum of models with different levels of complexity is used in climate system modelling to answer specific questions.

Uncertainty in our ability to predict social, technological and demographic changes into the future are dealt in part through modelling various emissions scenarios and incorporating different combinations of future weather factors such as temperature, humidity, rain patterns, land storage and other factors into models. These represent a range of driving forces and emissions to reflect current understanding and knowledge about underlying uncertainties. Four different 'storylines' (A1, A2, B1, and B2) were developed through IPCC processes in 2000 and cover a wide range of the main demographic, economic and technological driving forces of greenhouse gas and sulphur emissions (IPCC, 2000). Further information is at Appendix 1.

The IPCC Third Assessment Report (IPCC TAR) was released in 2001. The IPCC TAR reported on a few atmosphere-ocean general circulation models (AOGCMs) experiments conducted with the then new emissions scenarios. To establish the range of the sea level rise resulting from the different emissions scenarios, the results for thermal expansion and global average temperature changes from a simple climate model and seven AOGCMs were used (IPCC TAR WG1, 2001). Contributions from consideration of the continuing evolution of the ice sheets in response to past climate change, thawing of permafrost, and the effect of sedimentation was added (IPCC TAR WG1, 2001). Figure 3 illustrates some of the components of the TAR and differences with respect to earlier and later models.

Upon analysis of the complete range of AOGCMs and emissions scenarios and including uncertainties in land-ice changes, permafrost changes and sediment deposition, global average sea level was projected in the IPCC TAR to rise by between 0.09 to 0.88m by 2100, compared to 1990 levels (IPCC TAR WG1, 2001). Of the six emission scenarios, A1FI gave the largest sea level rise and B1 the smallest. The report provided decadal projections of sea level rise for the emission scenarios.

The complexity and resolution of global climate models have increased over time as the understanding of climate processes and interactions has improved with increasing availability of computing power (Figure 3).

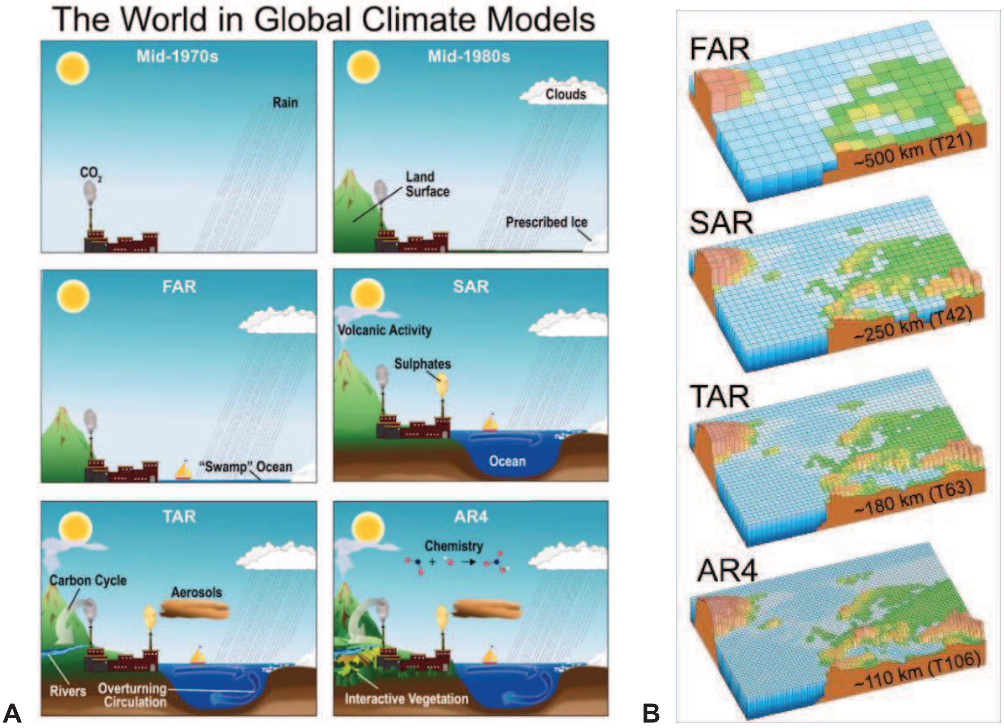

Figure 3: A) The complexity of climate models has increased over the last few decades. The additional physics incorporated in the models shown pictorially by the different features of the modelled world (IPCC AR4 WG1, 2007). B) Geographic resolution characteristic of the generations of climate models used in the IPCC Assessment Reports: FAR (IPCC, 1990), SAR (IPCC, 1996), TAR (IPCC, 2001), and AR4 (2007) Reproduced from: (IPCC AR4 WG1, 2007)

A major initiative by the World Climate Research Programme (WCRP) Working Group on Coupled Modeling (WGCM) was the coordination of sets of climate model experiments covering many aspects of climate variability and change that could be performed by as many modeling groups as possible with state-of-the-art global coupled climate models or AOGCMs (Meehl Covey, Delworth, Latif, McAvaney, Mitchell, Stouffer, and Taylor, 2007).

The WCRP was established in 1980 under the joint sponsorship of the International Council for Science (ICSU) and the World Meteorological Organization (WMO), and, since 1993, has also been sponsored by the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organisation (UNESCO) (World Climate Research Programme, 2012).

Climate model experiments performed in 2005 and 2006 formed the phase 3 of the Coupled Model Intercomparison Project (CMIP3). The CMIP3 at the time was the largest international global coupled climate model experiment and multimodal analysis effort ever attempted (Meehl *et al.,* 2007). The data available through these models, including both inputs and outputs are available for download and analysis to public research groups around the world. The results from CMIP3 were fed into the assessments for the IPCC AR4.

In the AR4 projections for climate change in the 21st century a subset of the emission scenarios was selected. This subset consisted of a 'low' (B1), a 'medium' (A1B), and a 'high' (A2) scenario. The decision to run three scenarios was based on the constraints on computer resources that did not allow for the calculation of all six scenarios. 17 AOGCMs for the three emission scenarios were used for the sea level rise projections. A scaling method was used to estimate the AOGCM mean results for the three missing scenarios B2, A1T and A1FI.

The IPCC AR4 at the time of publication predicted global mean sea level rise in the last decade of 21st century (2090-2099) to be between 0.18m and 0.59m above 1990 levels (IPCC AR4 WG1, 2007). The report acknowledged that the models did not include the full range of factors related to accelerating ice sheet melt due to uncertainties in the public literature at the time. The report provides an estimate that these additional effects could be between 0.1 and 0.2m by the end of the century (IPCC, 2007).

The sea level projections emerging from the IPCC AR4 as well as observed sea level measurements from tide gauge and satellite altimetry data (Church, Gregory, White, Platten, and Mitrovica, 2011) are reproduced in Figure 4. The Figure illustrates the tracking of sea level measurements toward the upper end of projections (red line between 1993 and 2010). The Figure also illustrates the wide range in projected sea levels, particularly toward the later part of the 21st century. The bars on the side of the figure illustrate particular ranges of projections from the six emissions scenarios.

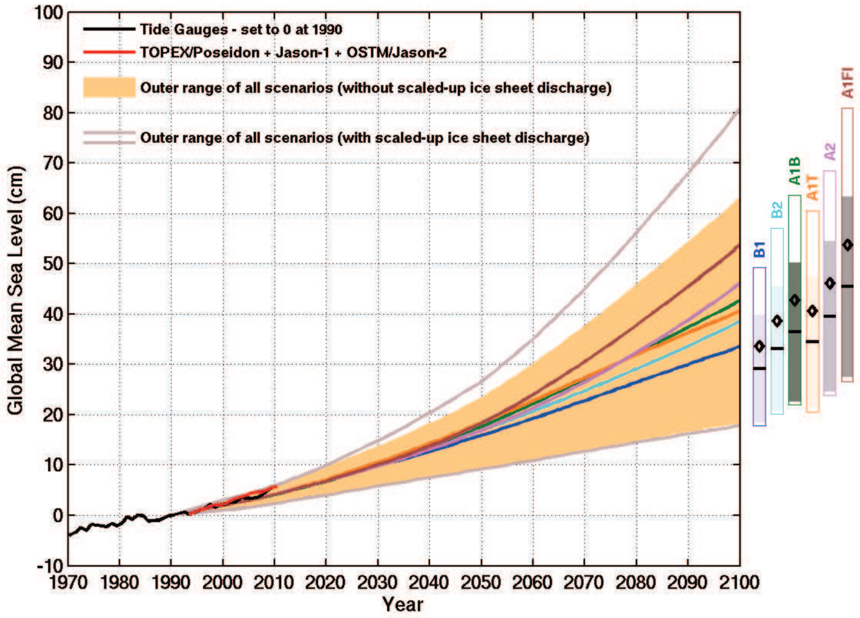

Figure 4: Projections of global-averaged sea-level rise for the greenhouse gas scenarios from the IPCC Emission Scenarios to 2100 with respect to 1990 (Church *et al*., 2011). The shaded region shows the full (5- to 95-percentile) range of projections, without scaled-up ice sheet discharge. The continuous coloured lines from 1990 to 2100 indicate the central value of the projections, including the scaled-up ice sheet discharge. The bars at right show the 5- to 95-percentile range of projections for 2100 for the various emission scenarios. The horizontal lines/diamonds in the bars are the central values without and with the scaled-up ice sheet discharge. The observational estimates of global-averaged sea level based on tide-gauge measurements and satellite-altimeter data are shown in black and red, respectively. The tide-gauge data are set to zero at the start of the projections in 1990, and the altimeter data are set equal to the tide-gauge data at the start of the record in 1993. The projections are based on the IPCC AR4 and is reproduced from Church *et al.* (2011) and available online at http://www.cmar.csiro.au/sealevel/sl_proj_21st.html#21C_ts,

In September 2008, a new set of coordinated climate model experiments were developed and will comprise the fifth phase of the Coupled Model Intercomparison Project (CMIP5) (Program for Climate Model Diagnosis and Intercomparison, http://pcmdi-cmip.llnl.gov/cmip5/index.html; Taylor, Stouffer, and Gerald, 2009). The models will utilise the same set of emissions scenarios as used in IPCC AR4 analyses. The CMIP5 will use a standard set of model simulations to:

- evaluate how realistic the models are in simulating the recent past
- provide projections of future climate change on two time scales, near term (out to about 2035) and long term (out to 2100 and beyond)

- understand some of the factors responsible for differences in model projections, including quantifying some key feedbacks such as those involving clouds and the carbon cycle.

The IPCC AR5 will provide an improved analysis of sea level change, and projections over coming decades. Information to be published in the AR5 will include:

- synthesis of past sea level change and its components
- models for sea level change
- projections of globally averaged sea level rise
- projections of the regional distribution of sea level change
- extreme sea level events
- potential ice sheet instability and its implications
- multi-century projections.

2.4. Sea level rise projections

Climate modelling and the projection of future sea level rise based on different scenarios is a complex field of research that is evolving rapidly. The projection of sea level rise is undertaken using the most up-to-date information available about earth systems and interactions derived from a vast range of research fields such as oceanography, meteorology, geology, palaeontology, physics, chemistry and biology.

The climate model predictions are an adequate means to gain insight into potential future scenarios of temperature, rainfall patterns and sea levels, and are the best methods currently available to predict potential future climates. Climate models present a range of projections related to future climates. These ranges reflect uncertainties based on what the future will be like (e.g. level of fossil fuel emissions, population and technological advancement) and our current understanding of climate and earth systems and their interactions (e.g. ice sheet melting and carbon cycles).

As research continues, more and more information and data is becoming available that can be used in climate models and used to test models, giving us an ever improving ability to project future climates.

Jurisdictions and organisations around the world have taken various approaches to developing and implementing ranges of projections for planning or risk mitigation approaches (Appendix 2). For instance, the US Army Corps of Engineers has published guidance for engineers dealing with planning and developing infrastructure on coasts to consider a range of different possible sea levels (low medium and high scenarios) to aid understanding and mitigation of the various possible impacts (Department of the Army - U.S. Army Corps or Engineers, 2011).

Several jurisdictions, including California and the Netherlands, have drawn on other modelling approaches (semi-empirical methods), to gain an understanding of possible worst-case scenarios for sea level rise (Sea Level Rise Taskforce of the Coastal and Ocean Working Group of the California Climate Action Team, 2010; Rahmstorf, 2007; Deltacommissie, 2008). These semi-empirical methods, which can give substantially higher projections than the process models used in the CMIP, are still a topic of discussion in relation to their validity, and it is advised by some authors that these be used with caution (Church *et al.*, 2011).

3. Analysis of process of NSW sea level rise benchmark calculation 2009

3.1. Derivation process for the NSW benchmarks in 2009

The derivation of the NSW sea level rise benchmarks and how the relevant information was used is set out in the *Technical Note: Derivation of the NSW Government's sea level rise planning benchmarks* (Department Environment, Climate Change and Water NSW 2009). At the time it was envisaged that a review of the benchmarks would be based on updated information, with the next review likely to coincide with the release of the Fifth Assessment Report (AR5) of the IPCC in 2014.

3.1.1. Components of Sea Level Rise in 2009 calculation

The components of the sea level planning benchmarks and the reference for the components are set out in Table 1.

Table 1: Components of the sea level rise planning benchmarks (Department Environment, Climate Change and Water NSW, 2009)

Component	Year 2050	Year 2100
Sea level rise (global mean)	30 cm *IPCC TAR 2001*	59 cm *IPCC AR4 2007*
Accelerated ice melt (global mean)	(included in above value)	20 cm *IPCC AR4 2007*
Regional sea level rise variation	10 cm *Interpolated from* McInnes *et al* (2007)	14 cm *Extrapolated from* McInnes *et al* (2007)
Rounding	-	-3 cm *Rounding to the nearest 10cm*
Total	40 cm	90 cm

3.1.2. Global Mean Sea Level Rise in 2009 calculation

The global mean sea level rise components of the benchmarks were derived from the projections from the IPCC TAR 2001 and IPCC AR4 2007. The 2050 component was derived from the IPCC TAR 2001 from the upper bound projection for the A1FI emission scenario (See Appendix 1 for a description of the emission scenarios). The 2100 component was derived from the IPCC AR4 2007 from the upper bound projection for the A1FI emission scenario.

3.1.3. Accelerated Ice Melt in 2009 calculation

The data from the models for the TAR already included a component for accelerated ice melt (IPCC TAR WG1, 2001) therefore an accelerated ice melt component was not added to the 2050 calculation.

However, the models for the AR4 were determined by the IPCC to not adequately represent the dynamic response of ice sheets to climate change, and it was noted that the TAR and AR4 projections of ice sheet contributions to both the 21st Century and longer term sea level rise may be underestimated (IPCC, 2007; Church, White, Aarup, Wilson, Woodworth, Domingues, Hunter, and Lambeck, 2008). The IPCC AR4, recognising this deficiency, increased the upper limit of the projected sea level rise by 10-20cm above that projected by the models. In the 2009 calculation, this upper bound of 20cm was added to the 2100 benchmark component to account for accelerated ice melt.

3.1.4. Regional Sea Level Rise in 2009 calculation

A regional sea level rise component was added to both the 2050 and 2100 benchmark calculations. The Technical Note published to explain the benchmarks, describes two different sets of data from CSIRO for regional sea level rise in NSW:

- A2 data from McInnes, Abbs, O'Farrell, Macadam, O'Grady, and Ranasinghe (2007) is used for the calculation of regional contribution to sea level rise in the benchmarks,
- A1B from CSIRO website (CSIRO, www.cmar.csiro.au/sealevel) was used to demonstrate regional impacts and illustrated sea level rise variations around Australia, showing estimates for NSW to be higher than global mean sea levels, and higher than other parts of the Australian coast.

Figure 5 (below) illustrating sea level projections under an A1B scenario was reproduced in the Technical Note to demonstrate the need for an additional regional component for NSW.

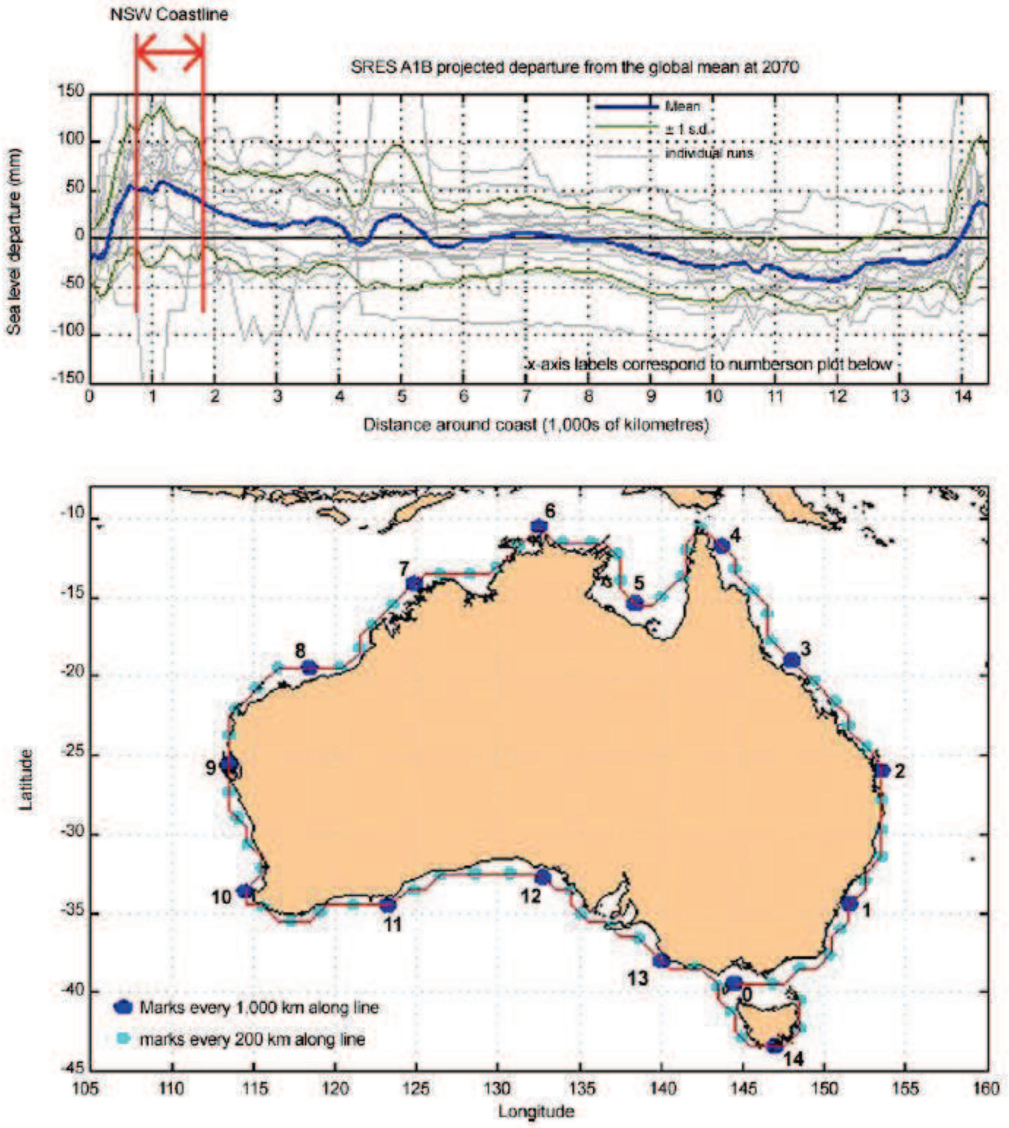

Figure 5: Figure 5 from *Technical Note: Derivation of the NSW Government's sea level rise planning benchmarks* Regional variations in projected sea level rise along the Australian coastline (CSIRO, www.cmar.csiro.au/sealevel)

The calculation of the regional sea level rise components (under A2 scenario) was based on the linear interpolation and extrapolation of values for 2030 and 2070 from a report by McInnes *et al* (2007). This report was commissioned by the then NSW Department of Environment and Climate Change to provide information on the impacts of climate change on coastal erosion along some regions of the NSW coast (McInnes *et al.,* 2007). The study was based on two distinct locations on the NSW Coast: the Clyde River/Batemans Bay systems (drowned river valley) and the Wooli Wooli river system (barrier estuary). These two locations were chosen to characterise the potential climate change impacts for the two geographically diverse coastal systems.

The study used a projection methodology commonly used by the CSIRO to explore the range of responses among different climate models. This approach was applied to wind speed. The two models that were found to be distinct for wind speed were then analysed in greater detail to derive other climate parameters such as wind direction, wind extremes, severe storms and regional sea level rise and these in turn were used to infer changes to the wave climate and storm surge return periods (McInnes *et al*., 2007).

Sea level rise was determined in the McInnes *et al.* (2007) study using the CSIRO Mark 2 and Mark 3 models with the IPCC A2 emission scenario. The A2 model in the 2007 paper was chosen by the researchers, who commented that it was considered to be a 'sufficiently conservative future scenario that is appropriate to base risk adverse planning decisions on'.

For both the CSIRO Mark 2 and Mark 3 models, thermal expansion was higher than the global average projections and was largest for the Mark 3 model (Batemans Bay, 2030: 0-0.04m, 2070: 0.08-0.12m; Wooli. 2030: 0.04-0.08m, 2070:0.08-0.12m). The report commented that results were associated with the projected stronger warming of the sea surface temperatures in this region and a strengthening of the East Australian Current.

In the 2009 calculation of benchmarks, a single data point for 2050 was used, as well as a single point for 2100. In doing this, the higher Wooli (not Batemans Bay) values for 2030 and 2070 were used and Technical Note indicates that a linear interpolation and extrapolation were performed to obtain estimates for the regional sea level rise component for 2050 and 2100 respectively. This resulted in the 10cm value for 2050 and 14cm for 2100 (see Table 1).

3.1.5. Addition of components to develop NSW sea level rise benchmarks

The 2050 benchmark was derived from the upper estimate of global mean sea level rise for that year as set out in the IPCC TAR 2001 (IPCC TAR WG1, 2001), with the addition of regional sea level rise component linearly interpolated from the McInnes *et al*. (2007) report.

The 2100 benchmark was derived from the upper estimate of global mean sea level rise for the last decade of the 21st century (2090-2099) as set out in the IPCC AR4 2007 (IPCC AR4 WG1, 2007), with an accelerated ice melt component added, and the addition of regional sea level rise component linearly extrapolated from the McInnes *et al.* (2007) report.

In drafting the Technical Note and determining the benchmarks in 2009, an approach was taken to round the value to the nearest 10cm, in acknowledgement of the degree of uncertainty surrounding the projections for future sea level rise.

These components are set out in Table 1.

3.2. Assessment of process to derive NSW benchmarks in 2009

The science behind climate change modelling and the projection of sea level rise is complex and evolving. Climate models are developed through a mechanism that draws together expertise from a wide range of science disciplines. The approach of utilising climate models and projections to inform our understanding of future climates and sea levels is an adequate approach given the current state of climate science.

3.2.1. Use of projections from climate model data

Each succeeding release of climate models has produced models that include a closer alignment to physical processes and improved resolution in terms of area. The models are evolving and with availability of improved input data, are consequently giving narrower ranges of projections. The development of global climate models for projections is discussed in section 2.3 of this report.

3.2.2. Use of upper level projections of sea level rise

The benchmarks developed in the 2009 calculation used the upper level of the TAR and AR4 projections for 2050 and 2090-99 (used for the year 2100) respectively. The decision to use the upper range of the models (upper bound of the 90% confidence interval), as opposed to the lower bound or mean, was made due to the finding that measurements of sea level rise appear to be tracking toward the upper level of model projections for the highest emissions scenario (A1FI) (Church *et al.,* 2011; Rahmstorf, 2007). The utilisation of upper levels reflects practice in various jurisdictions (Appendix 2) and aligns with a policy approach of risk mitigation.

It should be noted that use of the 2090-99 projection, which would give an average projection for 2095, as opposed to data for the year 2100 was based on available information at the time. Subsequent calculations by other groups have addressed this issue and have provided estimates for 2100 (CSIRO, www.cmar.csiro.au/sealevel).

3.2.3. Use of data derived from a single climate model rather synthesis of multiple models

In deriving the benchmarks for 2050 and 2100, a measure of regional contribution to sea level rise was incorporated (see Table 1). As discussed above in section 3.1.4., although two sets of regional projections for NSW were referenced in the Technical Note, OEH selected a set of data that was drawn from calculations that utilised a single model by McInnes *et al*. (2007).

As discussed above, the report by McInnes *et al*. (2007) was not developed to predict regional sea level rise, but rather to understand coastal erosion at two different sites projected under particular climate projection scenarios. The paper produced sea level rise projections for the two sites at 2030 and 2070 from two climate models, although only one was used for the data point in the 2009 benchmark calculation.

In choosing to use the McInnes *et al*., (2007) data rather than A1B emission data (also reproduced in the Technical Report), the OEH explained their choice based on the assumption that A2 scenario gave higher projections more closely reflecting observed measurements.

However, the CSIRO A1B data, available at the time, was developed using an array of 17 models' climate model simulations. These results were taken from CMIP3 (CSIRO, www.cmar.csiro.au/sealevel) and show projections also for 2030 (Figure 6) and 2070. The A1B data was freely available for download from the website for both 2030 and 2070.

As demonstrated in Figures 5 and 6, the CSIRO has demonstrated that a common feature of many model projections for Australia is a higher than global average sea level rise off the south-east coast. At the time, projections were used from the A1B emission scenario as regional projections were not available for A1FI without expert analysis.

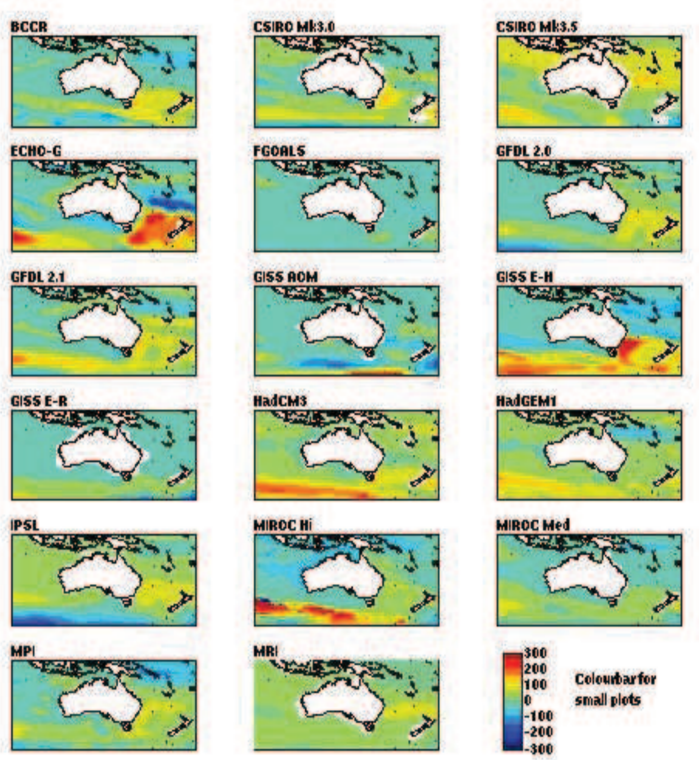

Figure 6: Projected departures from the 2030 global-mean sea level from 17 SRES A1B simulations Reproduced from: (CSIRO, www.cmar.csiro.au/sealevel)

The decision to use the single data point for regional rise from McInnes *et al* (2007) as opposed to other data such as from the A1B CSIRO projections is queried, however it is not clear that this would have made a major difference to the overall benchmarks. The McInnes *et al* (2007) derived numbers at 2030 and 2070 were 8 and 12cm respectively, while the CSIRO A1B data gave numbers of 11cm for 2030 and 16cm for 2070 (the latter numbers represent the upper bound of the 90% confidence interval (1.65 standard deviations from the mean) of the average sea level rise along the coast calculated in the preparation of this report from the CSIRO data) (CSIRO, www.cmar.csiro.au/sealevel).

As seen in Figure 5, there is considerable regional variation around the Australian coastline. The NSW coastline appears from the CSIRO modelling to be the region that will be most impacted by sea level rise, and that impact also varies along the NSW coast. Regional modelling capabilities will improve into the future with greater spatial and temporal resolution.

More advanced and affordable sensing, positioning and image processing technologies will produce better data and a clearer picture of changes in climate and sea level now and, by coupling to models, better projections into the future. Satellite data collection is an example of how new and more accurate sensing technologies can improve our understanding of climate systems and assist in mapping future possible flooding and inundation events in local council areas.

3.2.4. Use of linear interpolation and extrapolation

The OEH sought to develop benchmarks for 2050 and 2100, although they only had ready access to regional data for 2030 and 2070. In order to overcome this, linear interpolation and extrapolation was used to derive 2050 and 2100 values respectively. Given that OEH had only two data points, the form of the line that should have been used to connect the points is questionable. If, for example, the data were more exponential in form, like model sea level rise projections appear to be, linear interpolation and extrapolation could potentially result in numbers that are overestimated in middle ranges and underestimated in outer ranges. Further, prediction outside the range of observed years (such as in the case of linear extrapolation) makes a strong assumption about the continuity of the historical conditions underlying the model. The utilisation of experts in bringing together regional data from available modelling would potentially have overcome these issues.

In addition, the linear extrapolation appears to have been incorrectly calculated and therefore has possibly given a slight error for the 2100 component of regional sea level rise. The difference between 2030 at 8cm and 2070 at 12cm is 4cm. If one is to infer a linear trend this would equate to regional sea level rising by 1cm every 10 years. Based on that rate the regional values should be 10cm for 2050 and 15cm for 2100, instead of the 14cm for 2100. However, it should be noted that given the approach of rounding the Benchmark values to the nearest 10 cm (see section 3.1), this apparent error would not have made a difference in the final figure as a value of 94cm would have been rounded down to 90 cm.

3.2.5. Further comments on benchmark calculations

Overall, given the publicly accessible data available at the time, and the considerable expertise required to go to primary data sources such as the CMIP models for global and regional projections, without accessing experts it would not have been possible to obtain the most recent global mean sea level rise projections for both 2050 and 2100 from the same source.

There are inherent uncertainties in projecting future climate and sea levels. The approach used by the OEH is considered to be adequate, given the access that they had to available data in the literature at the time. Any minor errors emerging from the OEH processes such as through choices of data would seem to be outweighed by the uncertainties in the climate model projections. The evolving nature of our understanding of climate systems and dynamics, increasingly powerful computation and availability of massively more robust data, means that over time, and through utilisation of more advanced methods in the future, uncertainties related to climate models will be reduced.

Projections of sea level rise and assessment of the possible impacts on infrastructure under these conditions are important to enable councils and communities to manage and mitigate risk.

3.2.6. Expert Advice

Seeking advice from experts in developing benchmarks could have avoided several of the issues noted above and would have provided a more cohesive approach.

Australia and NSW have a considerable array of experts working in fields of relevance to sea level rise. These include:

- Australian Research Council (ARC) Centres of Excellence (COE) in Climate Systems Science; and the ARC COE in Geotechnical Science and Engineering
- National ICT Australia (NICTA) – expertise in data mining and information and communication technologies (ICT)

- INTERSECT Australia – e-research
- Bureau of Meteorology (BOM) and the National Tidal Centre
- CSIRO – Dr John Church, Dr Kathleen McInnes and colleagues are experts in sea level rise history and impacts, as well as modelling and satellite altimetry
- The Centre for Australian Weather and Climate Research (BOM and CSIRO)
- University of New South Wales Water Research Laboratory - coastal and other water engineers
- SMART Infrastructure Facility at the University of Wollongong
- CRCs including the CRC for Spatial Information and the Antarctic Climate and Ecosystems CRC (Dr John Hunter with expertise in modelling of extreme events and policy development including mechanisms to calculate allowances that take into account both the statistics of storm tides and sea level rise projections (Hunter, 2009; 2011)).

Recommendation 1 (Projections and review)

a) Given the expected ongoing release of new and updated sets of global climate models and projections, work should begin on establishing the appropriate framework for deriving updated sea level projections for NSW coastal locations and then refining these projections as yet further model outputs become available.

b) Considering the rapid pace of advancement in scientific understanding and computational and modelling capacity, and the improvement and lower costs of sensors, the NSW sea level rise projections should be reviewed at frequent intervals including at such time as the release of major new data for future climate projections.

c) Sea level rise projections for the NSW coast should be reviewed through a process of formal consultations with experts in fields including climate science, geotechnical engineering, oceanography, atmospheric science, mathematical modelling, statistics, computational science and computer engineering.

Recommendation 2 (Regional focus)

The NSW Government could look toward more regionally specific calculations that take into account specific sea level, topography, flood risk and other conditions along the NSW coast. This would allow factors such as probability of extreme events (e.g. severe storms and surges) and impacts to be incorporated into local planning.

4. Communication of sea level rise science

The OEH Technical Note for the derivation of the NSW sea level rise benchmarks is not as clear as it could have been in explaining the methodology and reasons behind the various components used in the benchmarks as well as the science behind the benchmarks. Any future calculation of benchmarks or projections of sea level rise should include a clear and accurate explanation of the process, and should be written in plain English to enable understanding by a broad audience.

There is considerable confusion and misunderstanding in the community regarding climate change and the impacts of sea level rise. In particular, communication of the likelihood of frequent revisions and refinements as more data becomes available and models improve is vital. This highlights the need for clear communications and more open discussion and access to data.

Particular issues arise in understanding climate and sea level projections and implementing these into practice in local government. Under the NSW coastal policy and local government frameworks, much of the responsibility for implementing sea level rise into planning strategies and approvals rests with councils. This could put them under pressure in interpreting what is complex science related to sea levels, as well as the complexities of coastal land issues and geomorphology, weather events, structural engineering, and the overlaying statistical uncertainty that is associated with projecting events out several decades. Greater technical support could be provided to assist in general planning and strategy development and also in assisting them to address specific questions as they emerge. This approach would assist councils in developing appropriate advice to land owners as required for development certificates.

Expertise could be brought together through a Technical Advice Centre to support local councils in interpreting and translating scientific findings into practice in infrastructure planning and risk management related to sea level rise and extreme events. The Technical Advice Centre ideally could be located at the headquarters of the Australian Research Council (ARC) Centre of Excellence in Geotechnical Science and Engineering (CGSE), headquartered at the University of Newcastle but involving as core partners the Universities of Newcastle, Wollongong and Western Australia. It was one of only 13 ARC Centres of Excellence awarded nationally in the most recent competitive round (2011). The ARC Centres of Excellences are the most prestigious research centres in Australia through which high-quality researchers maintain and develop Australia's international standing. They are selected through a highly competitive and open process that is independent of research field.

The CGSE’s focus on geotechnical engineering makes it an ideal organisation to translate the scientific findings into engineering solutions for local councils in infrastructure planning on coastal locations including for future sea level rise and extreme events. The CGSE already has considerable experience in working with organisations developing coastal infrastructure such as roads in a wide variety of conditions including sand dunes and areas affected by soil erosion. The CGSE would coordinate and collaborate with other centres of expertise in Australia as mentioned in section 3.2.6., ensuring that councils receive the best and most up-to-date information and advice. A further advantage of the Technical Advice Centre being headquartered in Newcastle is its location in the Hunter region which is close to the central and north coasts of NSW, which have been identified as locations of particular focus in dealing with rising sea levels and inundations.

Recommendation 3 (Technical Advice Centre)

The NSW Government should explore the feasibility of establishing a Technical Advice Centre to provide support to local councils in interpreting and translating new scientific findings, and assisting councils in developing strategies, infrastructure planning, and appropriate risk management activities related to sea level rise and its associated impacts. Ideally this centre would be located within an appropriate centre of expertise in NSW, such as the Australian Research Council Centre of Excellence for Geotechnical Science and Engineering headquartered at the University of Newcastle. This centre should draw on other appropriate centres of expertise. The Technical Advice Centre could also coordinate the projection review activities in Recommendation 1.

Recommendation 4 (Communication)

The science behind sea level rise and future projections, as well as potential local impacts needs to be explained and available in plain English to local councils and members of the public. Communication material should be updated regularly, as this is a field where new data and new and updated models are constantly emerging. This information should be provided as supporting documentation to the NSW Government sea level rise polices, including s149 advice, Technical Notes and other material.

References

Australian Government - Department of Climate Change. 2009. “Climate Change Risks to Australia's Coast - A first Pass National Assessment.”.

Church, J A., T Aarup, P L. Woodworth, W S. Wilson, R J. Nicholls, R Rayner, K Lambeck, G T. Mitchum, K Steffan, A Cazenave, G Blewitt, J X. Mitovica, and J A. Lowe 2010. “Sea-Level Rise and Variability: Synthesis and Outlook for the Future.” in *Understanding Sea Level Rise and Variability, 1st Edition*, edited by J A Church, P L Woodworth, T Aarup, and W S Wilson. Blackwell Publishing Ltd.

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.

Church, J A., N J. White, T Aarup, W S. Wilson, P L. Woodworth, C M. Domingues, J R. Hunter, and K Lambeck. 2008. “Understanding global sea levels:past, present and future.” *Sustainability Science* 3:9-22.

CSIRO and the Australian Bureau of Meterology. 2012. “State of the Climate 2012.”.

CSIRO. n.d. “Sea Level Rise.” (http://www.cmar.csiro.au/sealevel/index.html).

Deltacommissie. 2008. “Working together with water - A living land builds for its future.”.

Department Environment, Climate Change and Water NSW. 2009. “Derivation of the NSW Government’s sea level rise planning benchmarks - Technical Note.”.

Department of Environment and Resource Management. 2012. “Queensland Coastal Plan - Coastal Hazards Guidleine.”.

Department of Environment, Food and Rural Affairs. 2009. “UK Climate Projections User Interface.” Retrieved March 2012 (http://ukcp09.defra.gov.uk/).

Department of the Army - U.S. Army Corps of Engineers. 2009. “Water resources policies and authorities incorporating sea-level change considerations in civil works programs.”.

Department of the Army - U.S. Army Corps or Engineers. 2011. “Sea-level change considerations for civil works programs.”.

Department of Transport - Coastal Infrastrucutre, Coastal Engineering Group. 2010. “Sea Level Chnage in Western Australia - Application to Coastal Planning.”.

Hunter, J. 2009. “Estimating Sea-Level Extremes Under Conditions of Uncertain Sea-Level Rise.” *Climatic Change*.

Hunter , J. 2011. “A simple technique for estimating and allowance for uncertain sea level rise.” *Climatic Change*.

IPCC. 2000. *IPCC Special Report Emissions Scenarios - A special report of IPCC working group III*.

IPCC 2007 2007. “Summary for Policymakers.” in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by S Solomon, D Qin, M Manning, Z Chen, M Marquis, KB Averyt, M Tignor, and HL Miller. Cambridge UK. and New York USA.: Cambridge University Press.

IPCC AR4 WG1. 2007. *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.

IPCC TAR WG1. 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.

Koninklijk Nederlands Meteorologisch Instituut. 2006. “KNMI Climate Change Scenarios 2006 for the Netherlands.”.

Koninklijk Nederlands Meteorologisch Instituut. 2009. “KNMI Climate Change Scenarios 2009 for the Netherlands.”.

McInnes, K, D Abbs, S P. O'Farrell, I Macadam, J O'Grady, and R Ranasinghe. 2007. “Projected changes in climatological forcing for coastal erosion in NSW.”.

Meehl, G A., C Covey, T Delworth, M Latif, B McAvaney, J F. Mitchell, R J. Stouffer, and K E. Taylor. 2007. “The WCRP CMIP3 Multimodal dataset - A New Era in Climate Change Research.” *Americal Meteorological Society* 1383-1394.

National Research Council. 1987. “Responding to changes in sea level: Engineering implications.”.

Program for Climate Model Diagnosis and Intercomparison. n.d. “CMIP5 Coupled Model Intercomparison Project.” Retrieved March 22, 2012 (http://pcmdi-cmip.llnl.gov/cmip5/index.html).

Rahmstorf, S. 2007. “A semi-empirical approach to projecting future sea-level rise.” *Science* 315:368-370.

Sea Level Rise Taskforce of the Coastal and Ocean Working Group of the California Climate Action Team. 2010. “State of California Sea Level Rise Interim Guidance Document.”.

Taylor, K, R J. Stouffer, and A Gerald. 2009. “A Summary of the CMIP5 Experiment Design (updated January 2011).” (http://cmip-pcmdi.llnl.gov/cmip5/docs/Taylor_CMIP5_design.pdf).

Victorian Coastal Council. 2008. “Victorian Coastal Strategy.”.

Victorian Department of Sustainability and Environment. 2011. “Understanding sea level rise and climate change.” (http://www.climatechange.vic.gov.au/__data/assets/pdf_file/0006/124935/Sea-Level-Rise-Factsheet.pdf).

“World Climate Research Programme.” 2012. Retrieved March 2012 (http://www.wcrp-climate.org/history.shtml).

Appendix 1 - Emissions Scenarios

The IPCC Special Report on Emissions Scenarios (SRES) (IPCC, 2000) was published in 2000 and provides greenhouse gas emissions scenarios that can be used to make projections of possible future climate change. These emission scenarios were used in the TAR 2001 and the AR4 2007.

This description of the emissions scenarios below has been quoted from the IPCC Special Report on Emissions Scenarios 2000.

The emission scenarios were developed to represent the range of driving forces and emissions to reflect current understanding and knowledge about underlying uncertainties. Four different storylines (A1, A2, B1, and B2) were developed and cover a wide range of the main demographic, economic and technological driving forces of greenhouse gas and sulphur emissions. For each storyline several different scenarios were developed using different modelling approaches to examine the range of outcomes arising from a range of models.

A1 scenario

The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis; fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B).

A2 scenario

The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change is more fragmented and slower than in other storylines.

B1 scenario

The B1 storyline and scenario family describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

B2 scenario

The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

Appendix 2 - Sea Level Rise projections in other jurisdictions

The Commonwealth government and most States and Territories have undertaken calculations for future sea level rise projections (Table A1). Jurisdictions have chosen various timeframes and levels to set benchmarks and projections for planning.

Table A1: Summary of Australian sea level rise planning benchmarks and projections, data sources and review timing

Jurisdiction	Benchmarks and Projections	Data	Review timing
Commonwealth	**Projections for 2030, 2070 and 2100** have been developed by the CSIRO, based on three different emissions scenarios relative to 1990 levels (metres) (Australian Government - Department of Climate Change, 2009) B1 A1FI High 2030 0.132 0.146 0.2 2070 0.333 0.471 0.7 2100 0.496 0.819 1.1	• IPCC AR4 • post AR4 data • CSIRO data	N/A
NSW	**NSW Sea Level Rise Policy Statement** (2009). Sea level rise increase of: ▪ 0.4m by 2050, ▪ 0.9m by 2100 (above 1990 mean sea levels)	• IPCC TAR • IPCC AR4 • CSIRO data	• On release of IPCC AR5
Victoria	**Victorian Coastal Strategy** (Victorian Coastal Council 2008) Planning authorities must plan for a sea level rise increase of 'not less than' 0.8 m by 2100.	• IPCC AR4	• National Strategy • With new scientific data becomes available
Queensland	**Queensland Coastal Plan** (Department of Environment and Resource Management, 2012) ▪ For development not subject to a development commitment: a sea level rise of 0.8m by 2100 must be taken into account by planning authorities. ▪ For development already subject to a development commitment: the level of sea level rise which must be taken into account depends upon the year in which the planning period ends. Annex 3 of the Queensland Coastal Plan (2011) sets out: 2050 – 0.3m; 2060 – 0.4m; 2070 – 0.5m; 2080 – 0.6m; 2090 – 0.7m; 2100 – 0.8m.	• IPCC AR4	
South Australia	**Policy on Coast Protection and New Coastal Development** (1991); **Appendix I of Coast Protection Board Policy Document** (revised 20 January 2012). New developments should take into consideration:		

	- 0.3m sea-level rise by 2050; - A further 0.7m sea-level rise between 2050 and 2100		
Western Australia	**Position Statement: State Planning Policy No. 2.6 State Coastal Planning** Policy Schedule 1 Sea Level Rise (Department of Transport - Coastal Infrastrucutre, Coastal Engineering Group 2010) 0.9m sea level rise must be taken into account when planning authorities consider the 'setback and elevation' for new developments to allow for the impact of coastal processes over a 100 year planning timeframe (i.e. 2010 – 2110).	▪ IPCC AR4	When the IPCC AR5 is finalised
Tasmania	No benchmarks	N/A	N/A
NT	No benchmarks	N/A	N/A

A2.1 Sea Level Rise Projections Internationally

Many international comparator jurisdictions have also undertaken calculations to project sea level rise over coming the coming decades with some studies out to 2200. Many of these, such as the Netherlands, UK, US Army (Corps of Engineers), and California look at a range of scenarios over various time periods to model potential impacts of future sea level rise in their regions as well as impact of future extreme events such as storms and flooding and inundation.

A2.1.1. The Netherlands

In the Netherlands, several studies have been undertaken over the last decade, to gain a better understanding of potential future sea level rise. These include studies by the Royal Netherlands Meteorological Institute (Ministry of Infrastructure and the Environment) - Koninklijk Nederlands Meteorologisch Instituut (KNMI) study from 2006 (Koninklijk Nederlands Meteorologisch Instituut 2006) (update in 2009 (Koninklijk Nederlands Meteorologisch Instituut, 2009)), as well as the Delta Commission Report of 2008 (Deltacommissie, 2008).

Table A2 – Sea level rise projections from the Delta Commission Report (Deltacommissie, 2008)

	KNMI 2006 'warm' scenario	Delta Committee upper limit scenario (excluding gravity effect)
Total ranges for 2100	+0.40 to +0.85 m	+0.55 to +1.20 m

A2.1.2. US Army Corps of Engineers (USACE)

The US Army Corps of Engineers have released guidance on how to account for future rises in sea level for the design, planning and construction of coastal civil projects. The USACE guidance of 2009 (Department of the Army - U.S. Army Corps of Engineers, 2009) and 2011 (Department of the Army - U.S. Army Corps or Engineers 2011) draws heavily on previous work of the National Research Council (1987) on sea level rise projections.

The USACE methodology provides projections from three different scenarios of low rise (set as a rise at the current rate of measured sea level rise), the intermediate rise scenario (approximately the range of IPCC AR4 (IPCC AR4 WG1, 2007)), and a high rise scenario out to 2100.

The USACE also advises engineers and planners utilising the guidance to incorporate projections of local conditions of sea level change. In implementing the guidance for planning and construction, the USACE advises to take into account all three scenarios and likely local impacts (Department of the Army - U.S. Army Corps or Engineers, 2011).

A2.1.3. California, USA

The California state government in 2008 directed state agencies to consider a range of sea level rise scenarios for the years 2050 and 2100 to assess project vulnerability, reduce expected risks, and increase resiliency to sea-level rise (Sea Level Rise Taskforce of the Coastal and Ocean Working Group of the California Climate Action Team, 2010). The recommendations on projections are in Table A3 and use the year 2000 as the baseline.

Table A3: California State Government sea level rise projections

Year		Average of Models	Range of Models
2030		0.18 m	0.13-0.21 m
2050		0.36 m	0.26-0.43 m
2070	Low	0.59 m	0.43-0.70 m
	Medium	0.62 m	0.46-0.74 m
	High	0.69 m	0.51-0.81 m
2100	Low	1.01 m	0.78-1.28 m
	Medium	1.21 m	0.95-1.52 m
	High	1.40 m	1.10-1.76 m

The State of California Sea-Level Rise Interim Guidance Document (Sea Level Rise Taskforce of the Coastal and Ocean Working Group of the California Climate Action Team, 2010) included the Table A3 above and noted that the projections do not account for catastrophic ice melting, so they may underestimate actual sea level rise. For dates after 2050, three different values for sea level are shown - based on low, medium, and high future greenhouse gas emission scenarios. It is understood that the modelling behind these values uses semi-empirical analysis with emission scenarios (Appendix 1) of B1 for the low projections, A2 for the medium projections and A1FI for the high projections.

In its second recommendation, the Guidance Document notes: “for projects with timeframes beyond 2050, it is especially important to consider adaptive capacity, impacts, and risk tolerance to guide decisions of whether to use low, medium, or high sea level rise projections. Due to differing agencies mandates, stakeholder input and other considerations, agencies may assess the adaptive capacity of a project or action differently.” (Sea Level Rise Taskforce of the Coastal and Ocean Working Group of the California Climate Action Team 2010)

A2.1.4. UK Department of Environment Food and Rural Affairs

The most recent version of the UK Climate Projections (UKCP) developed by the UK Climate Impacts Program (Oxford University), the UKCP09 provides sea level rise projections (Department of Environment, Food and Rural Affairs, 2009):

- of changes in absolute sea level for the UK as a whole.

- of changes in relative sea level for 12 km coastal grid squares.
- for the period 1999–2099.
- for three emissions scenarios Low (IPCC B1), Medium (IPCC A1B), and High (IPCC A1FI), plus a high risk, low probability scenario (High ++).

The High++ scenario range was included to account for worst case and long term contingency planning rather than day-to-day investment decision making (Department of Environment, Food and Rural Affairs, 2009). The High++ scenario utilises semi-empirical modelling methods.

Regional projections of changes in absolute sea level for the region immediately surrounding the UK, have been applied in UKCP09. Figure A shows the different sea level rise projections for four locations around the UK.

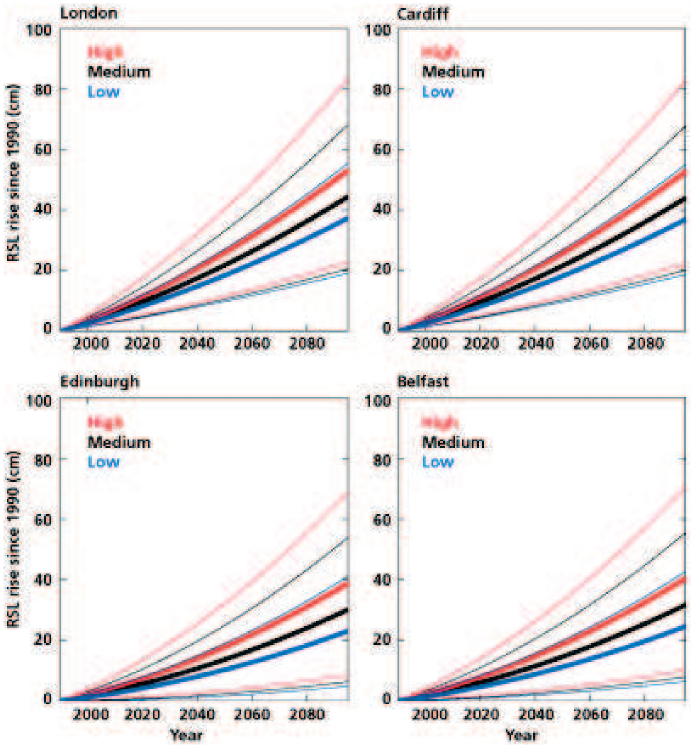

Figure A: Relative sea level rise over the 21st century showing central estimate values (thick lines) and 5th and 95th percentile limits of the range of uncertainty (thin lines) for four sample locations around the UK. Values are relative to 1990. (Reproduced from: http://ukclimateprojections.defra.gov.uk/content/view/1848/500/)