"*Widely Accepted by Competent Scientific Opinion*"
Sea Level Projections for the Shoalhaven and Eurobodalla Coast

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Abstract

The present New South Wales guidelines for the preparation of Coastal Zone Management Plans indicate that Councils should plan for sea level rise, and they should consider adopting projections that are *"widely accepted by competent scientific opinion"*

Shoalhaven City Council and Eurobodalla Shire Council commissioned a study to develop a planning framework for sea level rise. As part of that study, available local information was examined in detail. In particular, the study examined local variation in mean sea level along the coast between Sydney and the study area, both in the past and projected into the future.

Available data included both federal and New South Wales state government tide gauges and satellite altimetry data from offshore of the study area. The most recent model results from the Intergovernmental Panel on Climate Change were also examined and adjusted for projected regional effects.

The key findings of the study were that a) There has been no significant spatial variation in mean sea level change between Sydney and the study area during the past 20 years; b) The short term (~20 year) trends in ocean water level at Sydney and around the study area have been similar to globally averaged sea level rise c) There is unlikely to be a significant variation in the change of mean sea level between Sydney and the study area as sea levels rise; and d) projected regional impacts result in less than 10% variation from the global mean in waters offshore of the study area.

Introduction

This paper describes the decision making process leading to the recommendation of a sea level rise projection for adoption by Shoalhaven and Eurobodalla Councils (SCC & ESC). The work was undertaken as part of a project jointly commissioned by SCC and ESC, and funded by the Councils and the Office of Environment and Heritage (OEH). The project included the development of a sea level rise policy response framework for the Councils. Other aspects of the project are being presented in two companion papers at the 23rd

NSW Coastal Conference. Lord et al. (2014) discusses the practicalities associated with sea level rise triggers, a key aspect of the policy response framework; Lenehan et al (2014) presents detail on the way in which the framework is expected to operate in the context of future planning and adaptation.

While the Coastal Zone Management Plan (CZMP) guidelines recommend that councils should "*consider adopting projections widely accepted by competent scientific opinion*", it is clear that the adoption of any particular projection is not a decision that can be based on science alone. Relevant factors include legal interpretation, the present planning framework, the nature and desires of local communities, economics, the levels of pre-existing development, and an imperative to take a cautious approach that considers the well-being of future generations.

The state of understanding of sea level rise and climate change science in general has been a lightning rod for argument relating to the amount of allowance that should be made for sea level rise in planning and design. The focus on science is intriguing, particularly given the absence of any reliable means of predicting the long term behaviour of the global population in curbing greenhouse gas emissions. Accepting that the prevailing scientific understanding of the mechanisms that are presently affecting climate change is sound, the uncertainty associated with future human behaviour is of at least equal significance as that related to the uncertainty associated with science over multi-decadal time frames.

The most recent assessment report of the Intergovernmental Panel on Climate Change (AR5 of the IPCC) quantifies the uncertainty associated with future sea level rise given a particular projection of greenhouse gas emissions (or "radiative forcing"). This means that the decision of a local council to select a particular sea level rise projection should be largely influenced by a balance of the perceived risks associated with adopting a particular greenhouse gas emissions projection, and a highly qualitative assessment of what the future behaviour of the global population will be. Clearly there is a probability of occurrence associated with each projection and the IPCC offer no guidance in that regard, other than that all are possible.

Even so, the focus on science continues and it is necessary to address this, particularly given the implication that "locally relevant" data should be used. While we have found no evidence to suggest that sea level rise will occur in a non-uniform way along the South Coast of New South Wales, it is highly likely that local conditions relating to factors other than the physics of thermal expansion and melting ice, and an individual council's appetite for risk will have some bearing in the decision making. The existing legislation, policies and overall planning framework in New South Wales presently direct Councils towards a more risk averse (i.e. higher) sea level rise projection. Planning and design practice and common sense lead to the same conclusion.

The planning and legal contexts are presented first in the following sections. Subsequently, we examine the historical open coast sea level data available in the local area (taken as the New South Wales coast, south of Sydney). We then turn to the most recent projections of the IPCC, before discussing the reasoning leading to the recommendation of a given sea level rise projection. At the time of writing, neither ESC nor SCC have made a final decision on whether they will adopt these recommendations. The draft report was placed on public exhibition and forwarded to all NSW coastal councils for feedback.

Context and Approach

Legal and Planning Context

Sea-level rise has been recognised and planned for in New South Wales for at least the past 25 years. Over time, the legislation, regulations and guidelines applicable to planning for sea-level rise have become more complex. S733 of the *Local Government Act, 1993* aims to provide local councils with exemption from liability relating to coastal planning, providing that a genuine attempt is made (in "good faith") to comply with a relevant gazetted manual. At the present time, that manual is the Guidelines for Preparing Coastal Zone Management Plans (OEH, 2013). The guideline requires that councils should consider adopting projections that are *"widely accepted by competent scientific opinion".*

The present *Environmental Planning and Assessment Act, 1979* requires that the *New South Wales Coastal Policy 1997* be taken into account. The Coastal Policy indicates that (i) actions should be taken to prevent problems for future generations; and (ii) a "risk-averse" approach should be taken regarding land use planning for sea-level rise.

Our review of the applicable legislation and a range of legal advice indicated that, to take advantage of the s733 exemption, local councils cannot ignore future sea-level rise. Following the September 2012 repeal of the NSW Sea Level Rise Policy Statement (2009), local councils were given the responsibility of determining what projection of sea-level rise would be appropriate for their local situation. However the underpinning planning and legal framework encourages an approach that is cautious and does not unreasonably burden future generations with problems associated with, for example, a failure to plan adequately for future adaptation.

"Yabusame": Planning for Future Triggers of Unknown Time Frame

In an attempt to communicate the nature of a problem, the Japanese martial art *Yabusame* has been used for illustration. The allegory is illustrated in Figure 1.

In Yabusame, a mounted archer rides along a course, shooting at three targets spaced along the course as they pass. Considering Figure 1(top) where the rider starts riding and progresses from right to left, it should be clear that preparation and attention needs to focus on the first target. This is similar to acknowledging and beginning to plan for suitable adaptation of property and facilities considered to be imminently exposed to hazards relating to sea-level rise. These areas need immediate attention, planning, funding and focus; and are of key concern.

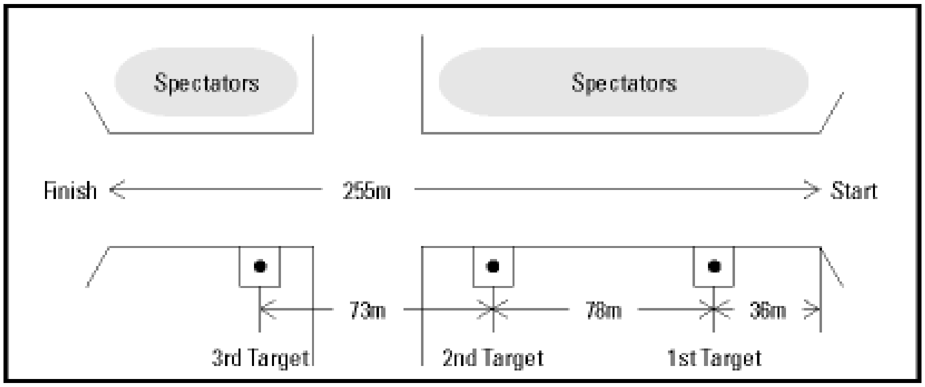

Figure 1 Top: Layout of Yabusame Grounds (Turugaoka Hachimanga Shrine, Bottom, Yabusame in Action.
http://web-japan.org/kidsweb/virtual/yabusame/yabusame01.html
http://travel.cnn.com/tokyo/play/yabusame-japanese-archery-action-917436

Beyond the first target, the immediate focus of the mounted archer is not required. It appears foolish to begin shooting arrows at the second and third target when you are at the start (right hand end) of the course. It is prudent to wait until you have dealt with the first target and gained a feel of conditions from that first shot, picked up momentum, gained a better appreciation of the speed of the horse and importantly, gotten closer to the target so that you have a better chance of being accurate. Similarly, there is great uncertainty surrounding projections of future sea level rise for medium and long term projections at the present time. While we don't want to overreact by firing towards these targets at the present time, we should still take precautions. We need to make sure that we have enough arrows in our quiver; we need to understand the nature of the task at hand, train ourselves to be prepared and have some feeling for the route we plan to take along the course.

In the present circumstances in New South Wales, it is foreseeable that a failure to plan and prepare adequately could be construed as a lack of "good faith", particularly considering that sea-level rise in New South Wales has been acknowledged as a concern for over 25 years. The challenge is to try and ensure that the planning strategies implemented now are not an overreaction that unnecessarily stifles the use of coastal land.

Hitting the First Target: Interpretation of Available Historical Evidence

Adaptation planning commonly involves the monitoring of physical parameters to identify when a particular “trigger” value might be exceeded. At the point in time when a trigger is reached, certain adaptation actions are proposed. These types of triggers are particularly important when considering developments that may be imminently at risk – In other words, our “first target”, continuing our reference to horseback archery.

In terms of sea-level rise, it is important to understand how sea levels are behaving (e.g. how they have been rising historically; the present sea level elevation).
Herein, we have focussed on mean sea level along the south coast of New South Wales. In terms of planning and engineering design, mean sea level is used as a basis for calculating suitable elevations (planning floor elevations, maritime facilities, seawall crest elevations), by adding local components including astronomical storm surge, catchment flooding, storm surge, runup and the like.

The variation of mean sea level was examined over a period of 18 years (from 1996 – 2013) using a variety of data sources, including primary tidal gauge stations operated by the National Tidal Facility (Fort Denison and Port Kembla), ocean tide gauges operated by Manly Hydraulics Laboratory (Middle Head in Sydney, Jervis Bay, Princess Jetty in Batemans Bay and Bermagui) and satellite altimeter data offshore of the study area, as provided by CSIRO.

The period 1996-2013 was chosen as this is the period over which reasonably complete data sets were available for all gauges and the satellite altimetry. Many gauges were installed by MHL along the south coast in the 1990’s, and the limiting site was Princess Jetty, which began recording around mid-1995. Satellite altimetry data is commonly considered reliable from 1993 onwards. It is important to make sure that the periods used are consistent, as variability relating to broad scale climate patterns such as ENSO can significantly affect calculated trends over very short periods. Trends covering different periods from different sites cannot be directly compared.

The available data for each site was processed by (i) removing data flagged as erroneous; (ii) averaging the recorded values for each year at each site; (iii) assembling an annual series of mean sea level for each site considered; and (iv) performing an ordinary least squares regression on each time series and (v) determining a representative trend over the 18 year period considered.

At this point, it is important to highlight that we do not consider these historical linear trends as representative of either long term historical, or future behaviour. Far more sophisticated means of removing the impact of ENSO and other sources of “noise” from the record are available, but were not considered necessary here. In particular, 1997, near the start of the period considered was a notable El-Nino

(High air pressure and relatively lower water level) year, and years near the end of the period (2010, 2011) contain significant La-Nina events (Low air pressure and relatively higher water levels). As noted above, the period chosen can significantly affect calculated rates. However, the key aim of this analysis was to determine whether there was any geographic variation in ocean water level trends. The linear trends calculated are presented in Figure 2. Notably, all gauges showed similar trends, responding in a similar way to variations in climate (i.e. all gauges tend to show comparable rises and falls from one year to the next). The gauge rates of rise all fell between 3.3 and 4.2 mm/yr. Notably, the altimeter data tended to show higher rates of rise (4.1-4.5 mm/yr) and not all of these differences can be accounted for by, for example, the effects of ongoing isostatic adjustment.

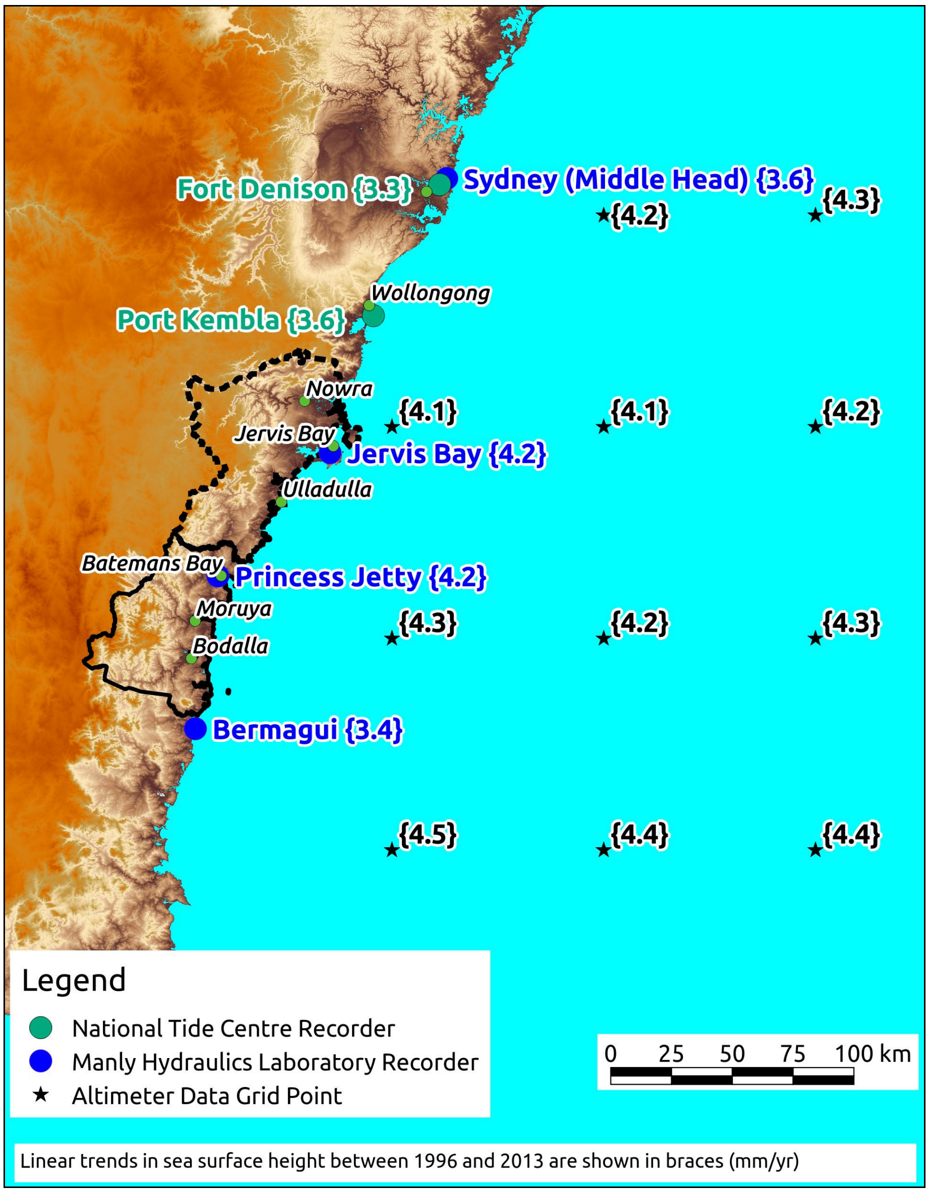

Figure 2 Linear sea level trends between 1996-2013 (mm/yr) at a variety of sites, South Coast NSW.

We were unable to find a specific geographic variation in the trends and patterns of mean sea level variation between Sydney and Bermagui. Furthermore, the rates calculated along this part of the coastline were similar to the global average estimated in Assessment Report 5 of the Intergovernmental Panel on Climate Change (IPCC AR5) over the same period. This strongly indicates that future sea-level rise offshore of the South Coast of New South Wales will be more or less the same as that experienced at Sydney.

Having established a lack of geographical variation, we conclude that the long tidal record at Fort Denison is the most useful for monitoring future sea level rise, in order to determine when particular water level triggers have been reached. The full record extends from 1886 and is provided in Figure 3. The annual mean sea level record at Fort Denison was also subjected to a number of filters which aimed to remove the sub-decadal time scale variations that have been widely linked to ENSO.

Four filters were applied:

- Butterworth 10 year: Utilising the GRETL (GNU Regression, Econometrics and Time-series Library) implementation of a second order low pass Butterworth filter with 10 year cutoff frequency
- Butterworth 20 year: Same as the above, but using a 20 year cutoff frequency.
- Hodrick Prescott: The Hodrick-Prescott Filter is filter commonly applied in econometrics to examine business cycles. For this study its implementation in the python statsmodels module was adopted. A lambda value of 400 was used and found by inspection to fit the underlying trend adequately.
- Penalised Regression Spline (PRS) Smoothing: This method fits a set of spline functions to the data set via least squares, but applies a roughness penalty via a set of smoothing splines.

The four resulting curves are shown in Figure 3. Of the methods used, the Butterworth 20 year, Hodrick Prescott and PRS curves all sit typically within 10mm of each other with the Hodrick Prescott typically sitting between the other two.

We highlight that, for the two methods that more comprehensively smooth out the underlying decadal scale variations (PRS and Hodrick Prescott), MSL at Sydney has been rising consistently since 1935 (over 80 years) albeit with a variable rate of rise to now be some 110-120mm higher than it was in 1935. Notable periods with increased rate of rise were during the 1940's and 1950's and since 1995.

Filters such as these can be utilised to help understand both the underlying "natural" variability and the impact of sea level rise from anthropogenic sources. The pragmatism of utilising the historical information to estimate the present day mean sea level, and thus determine when various triggers are realised, is explored in more detail in a companion paper to the present one (Lord et al. 2014).

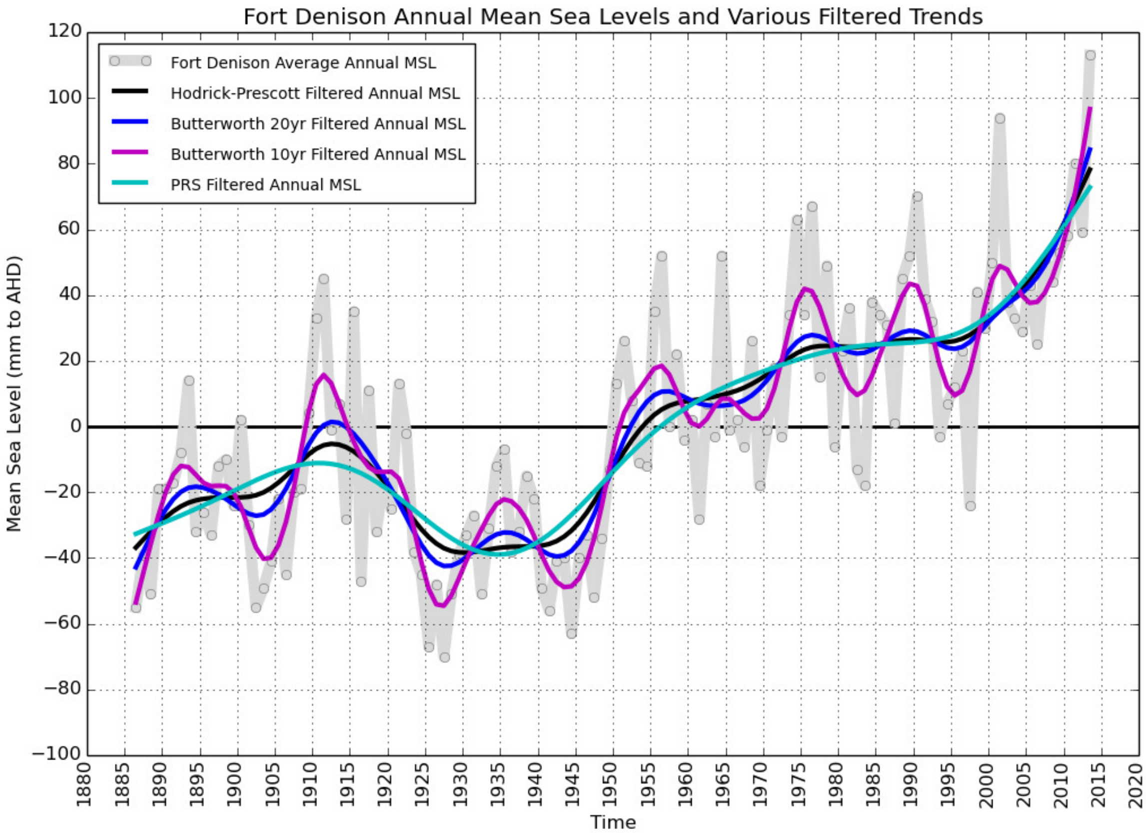

Figure 3 – Annual Series of Mean Sea Levels at Fort Denison and Various Filtered Trends

Hitting Subsequent Targets: Available Projections

The present CZMP Guidelines state:

> *"Councils should consider adopting projections that are widely accepted by competent scientific opinion"*

There are three key terms:

- Projections: Meaning that estimates of future climatic conditions, including anthropogenic effects, should be considered in planning for sea-level rise
- Widely Accepted: Opinions vary on the future of regional sea levels and it is not expected that a complete consensus will be achieved in the near future. However, the above statement prompts Councils to accept the prevailing scientific view
- Competent: The processes contributing to changes in local mean sea level are complicated and our review of recent developments in this field illustrates that the level of understanding required is substantial

Following consideration of the latest IPCC assessment report, the methods adopted in distilling available science, the transparent nature of the IPCC's review process and a variety of other literature sources surveying the opinions of scientists active in climate change research, we agree that the conclusions presented by the IPCC are reasonable and represent the views most widely accepted by the international climate change science community.

AR5 considers four *Representative Concentration Pathway* (RCP) scenarios. These are prescribed pathways for atmospheric greenhouse gas and aerosol concentrations, together with land use changes and are characterised by the radiative forcing, or warming effect of those changes. While consistent and plausible, the RCPs are not based on any given socio-economic scenario in the way that the four SRES (as used in AR4) were.

The four RCPs were characterised by Jubb et al (2013) and these are described in Table 1.

Table 1 Characterisation of RCP's adopted in AR5 (adapted from Jubb et al. (2013)

RCP	Radiative Forcing end of 21st Century	Equivalent Peak $C0_2$ (ppm)	Description	Comparable SRES Scenario
RCP 8.5	8.5	>1370	Very high baseline scenario. Little effort to reduce emissions and warming not curbed by 2100	A1FI
RCP6.0	6.0	850	Medium Scenario. Stabilises soon after 2100	A1B
RCP4.5	4.5	650	Medium Scenario. Stabilises soon after 2100	B1 (at 2100)
RCP2.6	2.6	490	Very Low "Ambitious" scenario. Emissions peak early at 3.0 W/m^2 then fall due to active removal of $C0_2$. Also known as RCP3PD	Lower than all SRES scenarios considered in AR4

In using their discretion, we understand that Councils are effectively being asked to make a judgement on the likelihood of these four RCP's and are called upon to select that projection which is most appropriate and defensible from a legal and planning perspective.

Even so, greenhouse gas concentration pathways do not provide us information on local mean sea levels. The four RCP's were used as inputs to many different Atmospheric Ocean Global Circulation Models (AOGCM's) as part of Phase 5 Coupled Model Intercomparison Project (CMIP5), the results of which are used in AR5.

A projected global mean sea level rise was calculated for each model, and the range containing 90% of the modelled projections (5-95%) is reported for each of the RCPs. However, although 90% of the modelled results fall within that range, the IPCC describes that range as only being *likely* to occur meaning, in the standard nomenclature of the IPCC, that the IPCC considers there to be a 66% likelihood that the global mean sea level rise will fall within that range, if the RCP in question actually arises.

Therefore, the 5-95% model spread range is actually transformed to a likelihood range of 17-83%. In effect, each of the four RCP's can be represented by three lines: a "High" line, which has a 17% chance of being exceeded, a "Middle" line, which has a 50% chance of being exceeded, and a "Low" line which has an 83% chance of being exceeded if that RCP occurs.

These global average lines need to be transformed to local conditions. The following effects are considered to have some effect on the local mean sea level rise:

- Glacial Isostatic Adjustment, Present understanding is that the coastline between Sydney and the South Coast is adjusting evenly following the last glacial period. This adjustment is expected to account for a few centimetres of relative sea level fall by 2100;
- Gravitational Effects relating to changes in the gravitational field of the earth following redistribution of ice mass around the globe as it melts and flows into the ocean. The effect of this offshore of New South Wales is expected to be small (~1% of total sea level rise by 2100);
- Due to changes in global circulation, there are expected to be changes in sea level along the east coast of Australia, largely related to changes in the dynamics of the East Australia Current. Overall, these changes are expected to relatively increase mean sea level along the coast of NSW compared to the global average, but by less than 10% of the global average mean sea level rise.

The differences between Sydney and the south coast due to these changes are small compared to the expected global mean sea level rise. These adjustments were made to the four global projections of mean sea level rise to estimate locally relevant mean sea level values for the SCC and ESC Local Government Areas. The resulting "High" lines for all four RCP's are presented in Figure 4. To make the projections relevant to present day conditions, they have all been zeroed to 2015. It is also important to note that there is still a significant estimated chance (around 1 in 6) that these "High" lines would be exceeded, if the RCP in question is precisely realised.

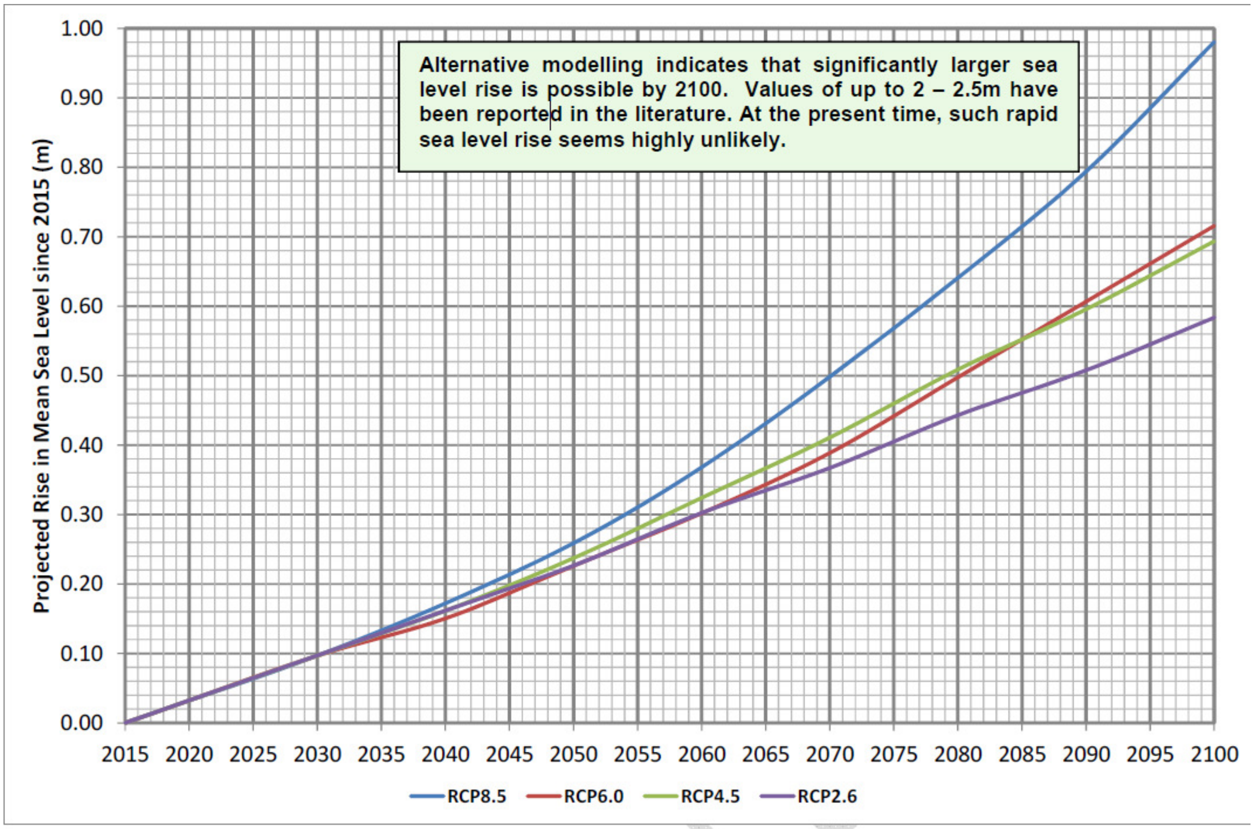

Figure 4 Adjusted NSW South Coast Sea Level Rise Projection "High" Lines for AR5 RCP's

Perhaps the most important feature of Figure 4 is the notable absence of any significant difference between projections by 2050 (less than 40mm). The projections diverge somewhat in subsequent decades.

Making a Decision

As part of the study, a recommendation was made to Council regarding the projection that they should adopt. The following information was taken into account considering the existing legal, planning and risk management environment; the responsibilities of Councils and context within which they need to make decisions; and the present state of uncertainty relating to the science and the future intensity of global fossil fuel use. Aspects of this were discussed as part of risk management workshops held with staff from OEH, the Department of Planning and both Councils.

This process led to the following conclusions:

- That RCP2.6 is not as plausible as the other projections and should not be used for coastal management and planning at this time;
- Attendees at the risk assessment workshops undertook a consequences assessment which indicated that the future adverse consequences of adopting a sea-level rise projection that is too low are more severe than through adopting

a projection that is too high. Importantly this did not rule out the potential for negative consequences from adopting a projection that is too high;

- That planning guidelines, legislation and legal advice encourage a cautious approach that promotes the selection of a higher sea-level rise projection; and
- That, following AR4, there was a tendency both in Australia, and globally, to adopt projection based on the fossil fuel intensive scenario (A1FI) for planning purposes. That scenario is most similar to RCP8.5 in the most recent IPCC assessment and there are apparently no widely supported arguments for a change from this approach.

Due to these points, RCP 8.5 was recommended as a suitable and defensible basis for sea level rise projection at the present time. Subsequent to research undertaken as part of this study, we note that the recent information indicates that global emissions from recent years are tracking on top of the RCP8.5 projection (Fuss et al. 2014), as shown in Figure 5. Of course, there is a long time to go until 2100 for significant changes in this trend to occur.

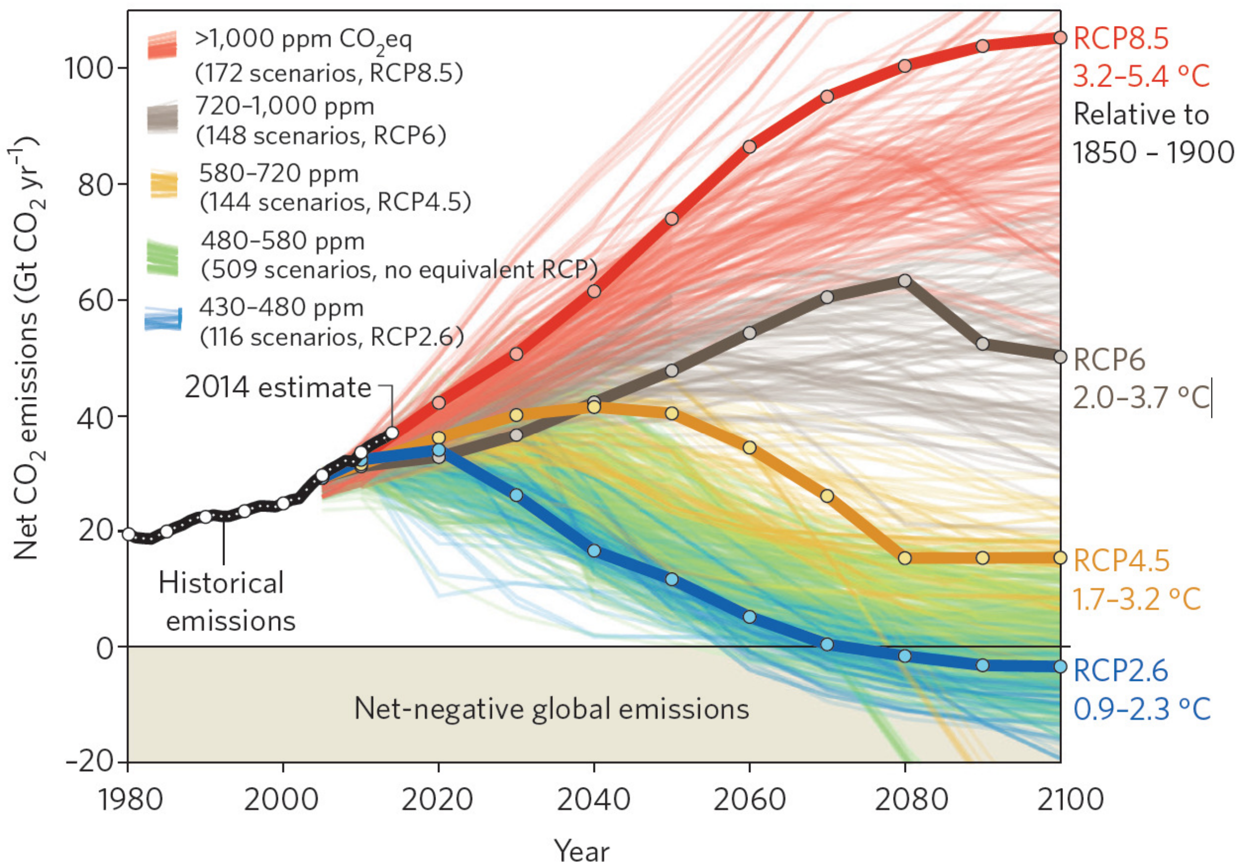

Figure 5 Figure from 1(a) Fuss et al, 2014, Illustrating the Present Emissions Pathway.

Discussion and Conclusions

Determination of an appropriate projection still results in some confusion. For each projection (i.e. each RCP) there is a spread of model predictions reported by the IPCC in AR5, resulting in three lines being presented in AR5 (for 17%, 50% and 83% exceedance probabilities, respectively the "high", "mid" and "low" lines as discussed above). It is erroneous to consider each of these lines as individual "projections" in themselves. Instead, they represent the spread of modelled sea level rise predictions arising from different models simulating the selected RCP. Review of the technical detail in AR5 indicates that the model results are approximately normally distributed, meaning that model results tend to cluster around the Mean/Median or 50% values. However, having adopted a particular RCP as appropriate, selection of the median value for planning is effectively planning for a 50% chance of failure.

We see two ways forward with this:

1. Undertaking a full risk assessment which looks at the distribution of results (effectively uses all three lines, or by statistically synthesising potential sea level rise projections from the distribution represented by these three lines) and executes a stochastic simulation of the resulting consequences and risk; or
2. Select the "high" line as an appropriate, conservative default value.

The second approach represents a more traditional engineering or planning approach that would normally be adopted, to assure an acceptably high level of protection against failure over the design life of development.

Even so, there are some, albeit limited, examples of local research that have undertaken the stochastic approach outlined in Item 1, resulting in support for adoption of the 'high' line as the basis for planning, although these methods are still evolving.

Firstly, Hunter et al. (2013) calculated an appropriate "allowance", at a number of sites globally, for sea level rise by 2100, where the allowance was a vertical distance by which an asset would need to be raised under a rising sea level so that the present likelihood of flooding would not have increased at 2100. The calculation was based on AR4's A1FI emissions scenario. For Fort Denison, an allowance of 0.88m (between 1990 and 2100) was calculated, directly comparable to the previous NSW sea-level rise policy value of 0.90, which in turn was based on the comparable "high" line of A1FI from AR4. Accordingly, a probabilistic assessment based on oceanic inundation indicated that the 'high' line is appropriate in the context of the NSW South Coast (for which Fort Denison is a reasonable proxy).

Secondly, Woodroffe et al. (2012) utilised the stochastic sampling of sea level rise projections in simplified beach erosion modelling software. When compared to the deterministic approach (application of the previous NSW sea-level rise policy values) the stochastic approach returned erosion distances for the 95%

exceedance level that were comparable but less than (around 80% of) the calculated deterministic recession distance at 2100. This shows that, to provide a suitably high level of protection against failure (say 95% over a design life extending out to 2100), the high line can be adopted but may be a moderate overestimate in terms of coastal erosion.

These types of analyses can be complex, are specific to each particular site and the methods are still evolving. A clear accepted "standard" approach is not yet available.

In summary, selection of the most fossil fuel intensive projection (RCP8.5) is guided by present legislation, legal advice and the planning documentation. Selection of the "high" line of uncertainty representing the AR5 model results spread is a function of good cautious engineering and planning practice which aims to defend development against failure during its design life. These two selections are different, and we suggest that selection of the projection is the aspect over which some decision makers may exercise discretion. However, on the basis of legal advice, the existing planning framework, the responsibilities of councils in New South Wales and recent information which indicates that the world is closely tracking RCP8.5 in terms of carbon emissions, we have recommended that RCP8.5 be adopted as the basis for sea-level rise planning by Shoalhaven City Council and Eurobodalla Shire Council at the present time.

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