Expert Opinion -

Coastal flooding and adaptation

Amendment C69 to the Moyne Shire Planning Scheme

Victorian Planning Authority
Panel Hearing August 2022

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Report Prepared For:	Glenelg Hopkins Catchment Management Authority (GHCMA)
Instructed By:	Graeme Jefferies (GHCMA)
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1. **Report Author**

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Qualifications:

- B.E. (Hons), University of Auckland, 1996
- PhD, University of Auckland, 1999

Affiliations:

- Member, Institute of Engineers Australia, Chartered Professional Engineer
- Committee Member, Engineers Australia, South-Eastern Australia Coasts Ocean and Port Engineering Panel
- Member, River Basin Management Society
- Member, Australia New Zealand Geomorphology Group

Area of Expertise

Key areas of expertise relevant to this report are summarised below.

- Water and Coastal Engineering including hydrologic and hydraulic modelling for riverine and coastal flood investigations, coastal processes (erosion & inundation hazard assessment) and coastal adaptation

Statement of Expertise

With my qualifications and experience, I believe that I am well qualified to provide an expert opinion on coastal flooding matters relevant to Amendment C69 to the Moyne Shire Planning Scheme.

Specifically, I have:

a. Been the project manager, and technical lead or expert on 18 major coastal hazard studies across Australia, several of which included adaptation planning elements,
b. As a technical expert I contributed to the upcoming update to the Victorian coastal hazard guidelines as part of the Victoria's Resilient Coast - Adapting for 2100+ program.
c. Been the project manager, and technical lead on at least five large scale flood studies where the coincidence of catchment and coastal flooding has been a consideration and over 14 other catchment flood studies,
d. Authored the upcoming Victorian Guideline for Modelling the Interaction of Catchment & Coastal Flooding (DELWP, 2022).
e. Been assisting Melbourne Water with scoping their requirements for undertaking a detailed coastal hazard and adaptation study for the Western Treatment Plant.
f. My qualifications are detailed in Appendix A.

2. **Instructions**

I have been instructed by Graeme Jeffery (Senior Statutory Water Planner, Glenelg Hopkins CMA) on behalf of the Glenelg Hopkins Catchment Management Authority and in support of Moyne Shire, to provide expert evidence in relation to relevant coastal flooding and adaptation matters associated with the proposed Amendment C69 to the Moyne Shire Planning Scheme.

Specifically, I have been requested to provide an expert witness statement in relation to the following aspects:

- The dependence of the predicted sea level rise trajectories on emissions scenarios.
- A description of the IPCC Emissions scenarios including the SSP8.5 Low Confidence scenario.
- An overview of the United Nations Emissions Gap Report 2021 and what it means in terms of evidence of actual reduction in emissions.
- Victoria's adoption of the SSP8.5 scenario in Coastal Policy.
- The rate of local sea level rise as recorded by the Portland tide gauge.
- Projected timeframes to reach 0.8 and 1.2m sea level rise based on analysis of the Portland Tide Gauge data and predicted emissions scenarios.
- Projected operable lifespan of the proposed controls.
- Validity of the CMAs proposed approach to the NFPL.
- The logic for the CMAs proposed approach to increase the NFPL in concert with locally observed change in mean sea level as recorded by the Portland Tide Gauge.

3. **Basis of this Report**

This expert report is based on the following report which I prepared for the Glenelg Hopkins Catchment Management Authority to provide a clear logic for identifying the circumstances under which sea level rise risk management decisions with potential to affect land development prospects (such as raising of the Nominal Flood Protection Levels, NFPLs) may be justified:

- **Streamology (2022). Tide Gauge Trigger Levels for Sea Level Rise Adaptation Pathways, Report prepared for the Glenelg Hopkins Catchment Management Authority**

The following additional supporting information and technical reports have also been examined to address the specific scope of this report, including:

- Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors), 2019, Australian rainfall and runoff: a guide to flood estimation, Geoscience Australia Commonwealth of Australia
- Cardno 2019. Translation of the Port Fairy Coastal Hazard Assessment, prepared for Moyne Shire Council, Melbourne, VIC
- Church et al., 2016: Sea-Level Rise and Allowances for Coastal Councils around Australia – Guidance Material. CSIRO Report 64 pp.
- Dayan H, Le Cozannet G, Speich S and Thiéblemont R (2021) High-End Scenarios of Sea-Level Rise for Coastal Risk-Averse Stakeholders. Front. Mar. Sci.
- De Dominicis, M., Wolf, J., Jevrejeva, S., Zheng, P., & Hu, Z. 2020. Future interactions between sea level rise, tides, and storm surges in the world's largest urban area. Geophysical Research Letters, 47
- DELWP (2021). Draft Marine and Coastal Strategy - draft for consultation, Department of Environment, Land Water and Planning, State of Victoria
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- Haigh I., Wijeratne E.M.S., MacPherson L., Pattiaratchi C., Mason M., Crompton R., and George S. (2014) Estimating present day extreme water level exceedance probabilities around the coastline of Australia: tides, extra-tropical storm surges and mean sea level. Climate Dynamics, 42, 121-138.
- HARC (2021) Port Fairy Summary Report, report prepared for Moyne Shire Council
- Hunter, J.R. Church, J.A. White, N.K, and Zhang, X. 2013. Towards a global regionally varying allowance for sea level rise, Ocean Engineering, 71, p17-27
- Hunter, J.R. 2013. Derivation of Revised Victorian Sea-Level Planning Allowances Using the Projections of the Fifth Assessment Report of the IPCC, Research conducted for The Victorian Coastal Council, Flexible Contracting Services, Tasmania
- Insurance Council of Australia 2022. Climate Change Impact Series: Flooding and Future Risks, Report prepared for the Insurance Council of Australia by James Cook University in association with Risk Frontiers
- IPCC, 2000: Special Report on Emissions Scenarios, A Special Report of the Working Group III of the Intergovernmental Panel on Climate Change.

- IPCC, 2001: Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Integovernmental Panel on Climate Change [Watson, R.T. and the Core Writing Team (eds.)]. Cambridge University Press, Cambridge,
- United Kingdom, and New York, NY, USA, 398 ppIPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp
- IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA
- IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.
- IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.
- IPCC, 2022: Summary for Policymakers [H.-O. Pörtner, D.C. Roberts, E.S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem (eds.)]. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3–33.
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- Meinshausen, M. Nicholls, Z. Lewis, J. Gidden, M. Vogel, E. Freund, M. Beyerle, U. Gessner, C. Nauels, A. Bauer, N. Canadell, J.G. Daniel, J. John. A. Krummel, P. Juderer, G. Meinshausen, N. Montzka, S. Rayner, P. Reimann, S. Smith, S. van den Berg, M. Velders, G. Vollmer, M. and Wang, R. (2020). The shared socio-economic pathway (SSP) greenhouse gas concentrations and their extension to 2500, Geoscientific Model Development, 13, 3571-3605, Published by Copernicus Publications on behalf of the European Geosciences Union
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- Schalm, C.R. Glendon, S. and Duffy, P.B 2020. RCP8.5 tracks cumulative CO_2 emissions, Proceedings of the National Academy of Science, vol. 117, no. 3
- Sweet, W.V., B.D. Hamlington, R.E. Kopp, C.P. Weaver, P.L. Barnard, D. Bekaert, W. Brooks, M. Craghan, G. Dusek, T. Frederikse, G. Garner, A.S. Genz, J.P. Krasting, E. Larour, D. Marcy,

J.J. Marra, J. Obeysekera, M. Osler, M. Pendleton, D. Roman, L. Schmied, W. Veatch, K.D. White, and C. Zuzak, 2022: Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines. NOAA Technical Report NOS 01. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 111 pp.

- United Nations Environment Programme (2021). Emissions Gap Report 2021: The Heat Is On – A World of Climate Promises Not Yet Delivered. Nairobi
- United Nations Framework Convention on Climate Change (2021). Nationally Determined Contributions under the Paris Agreement. Synthesis Report by the Secretariat. 17 September.
- Wood, M., Haigh, I. D., Le, Q. Q., Nguyen, H. N., Tran, H. B., Darby, S. E., Marsh, R., Skliris, N., Hirschi, J. J.-M., Nicholls, R. J., and Bloemendaal, N.: Climate-induced storminess forces major increases in future storm surge hazard in the South China Sea region, Nat. Hazards Earth Syst. Sci. Discuss. [preprint]
- Relevant guidelines and standards, including:
    - DELWP's Guidelines for Development in Flood Affected Areas (2019)
    - Handbook 7, Australian Disaster Resilience Handbook Collection - Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia
    - Australian Standard AS 5334-2013 Climate Change Adaptation for settlements and infrastructure - a risk based approach
    - CSIRO's Sea-Level Rise and Allowances for Coastal Councils around Australia - Guidance Material (Church et al, 2016: Sea-Level Rise and Allowances for Coastal Councils around Australia – Guidance Material. CSIRO Report 64 pp)

This report has been prepared in accordance with the relevant procedures and practice notes applied by Planning Panels Victoria on Expert Evidence. I have read the "Guide to Expert Evidence" and are aware of my overriding duty to assist the Panel on matters relevant to my expertise.

4. **Background**

4.1. **What is Adaptation?**

Using the definition from the Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report (IPCC, 2022), adaptation is defined as:

The process of adjustment to actual or expected climate and its effects to moderate harm or take advantage of beneficial opportunities.
Adaptation means adjusting decisions and activities, to manage risks and harness potential opportunities.

The effects of climate change, which include sea-level rise and changes in the occurrence of extreme events, have the potential to significantly impact the livelihoods and lifestyles of coastal residents and the natural environment. So, the decisions and actions that help to prepare for the adverse consequences of climate change are known as climate change adaptation (Coast Adapt, accessed 18/08/2022).

There are a range of adaptation options, such as planning and policy actions, disaster risk management, early warning systems, climate services and risk spreading. Within the Marine and Coastal Policy (2020) *adaptation is embedded as a core component of planning in the marine and coastal environment and is used to manage uncertainty and build resilience.* The policy also notes that adaptation will need to be responsive to local conditions.

4.2. **Adaptation Pathways**

The following discussion is taken from Streamology (2022) and describes what an adaptation pathway is and why it is an appropriate approach to flood management and planning when dealing with uncertainty such as climate change and predicted future sea level rise. The pathway approach is also specified within the Marine and Coastal Policy (2020) with respect to decision making around coastal hazards, such as coastal flooding.

To be adaptive to the uncertainty in the future projections of sea level rise requires the timing of any proposed action to be considered. Acting too soon can risk locking into inappropriate outcomes from economic, social, or cultural perspectives but acting too late can risk locking in considerably higher impacts later (CoastAdapt, accessed 12/10/2021). At the same time, risk management needs be able to respond effectively to new information and observed change in the physical environment (Hunter et al, 2013). This is especially so if observed change outstrips the projected rate of change compressing the timeframe over which effective action can be implemented. A pathways approach maps out a range of potential adaptation options and the estimated timeline (based on best available information) for when it is likely that decisions will need to be made to guide an orderly adaptation process. This enables decision-makers to identify critical thresholds and decision points for adopting different adaptation pathway options as new information becomes available. Such "new information" could be realisation that the rate of sea level rise is outstripping the projected rate of change, resulting in the need to bring forward a decision point for taking an alternative pathway. If it is apparent at this future point in time that none of the pre-determined (existing) pathway options are going to be adequate, it may be necessary to identify an entirely new pathway.

There are a range of adaptation pathways that could be applied to decision making for development of low-lying land and the exposure of coastal communities to worsening flood risks (see Haasnoot *et al* 2019) but there are considerable challenges in managing decision making given the uncertainty in future sea level and rates of change (e.g., Stephens *et al* 2018; Kool *et al* 2020) and the reluctance of decision makers to act on uncertain information.

It is therefore important to identify thresholds at which the adopted pathway is likely to become ineffective in meeting objectives and a new pathway for action is necessary. In other words, the approach involves establishment of a logic for anticipating what "forks in the decision-making road" might arise and what appropriate paths leading away from the fork might look like so that decisions can be made more easily. Thresholds may be related to flood protection measures like the Nominal Flood Protection Level (NFPL) used to set building floor levels or the level of service provided by assets like stormwater drains and roads. An example adaptation threshold would be an increase in mean sea level to a point where storm-tide flooding becomes too frequent for the local community to function (Stephens *et al* 2018); or where the NFPL applied to protect properties from a 1%AEP flood is no longer adequate because the 1%AEP flood level has increased because of sea level rise.

Monitoring indicators of change such as the rate of sea level rise or the frequency of flooding can be used to trigger adaptive actions ahead of reaching a given threshold beyond which moving to a pathway enabling effective avoidance or management of risk will become more difficult and expensive or potentially impossible. The trigger must provide sufficient lead time to adapt before the unacceptable risk threshold is reached.

A 'signal' of change is needed to alert the decision maker of a pending decision point 'trigger'. It essentially functions as ‘early warning’ that a critical adaptation threshold is approaching and should initiate commencement of preparations for making an informed decision as to the best adaptation pathway option to take for avoiding or minimising likely impacts if a "do nothing" approach is taken and the impact threshold is reached (Stephens *et al* 2018). These concepts are shown in Figure 1.

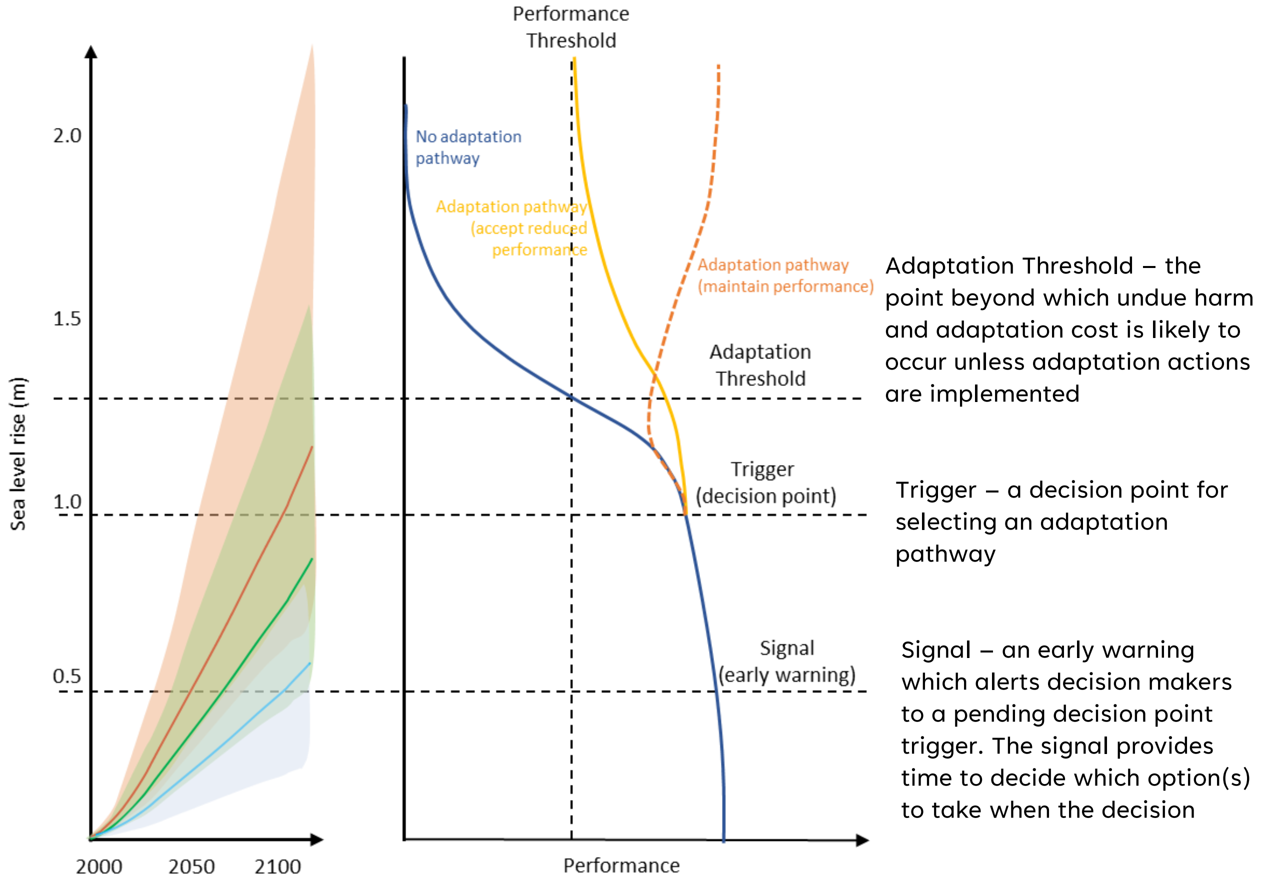


Figure 1 Sea level rise projections for different emissions scenarios with their confidence intervals along with a schematic showing the threshold, trigger, and signal in terms of sea level rise and performance threshold and adaptation pathways (adapted from Stephens et al 2018)

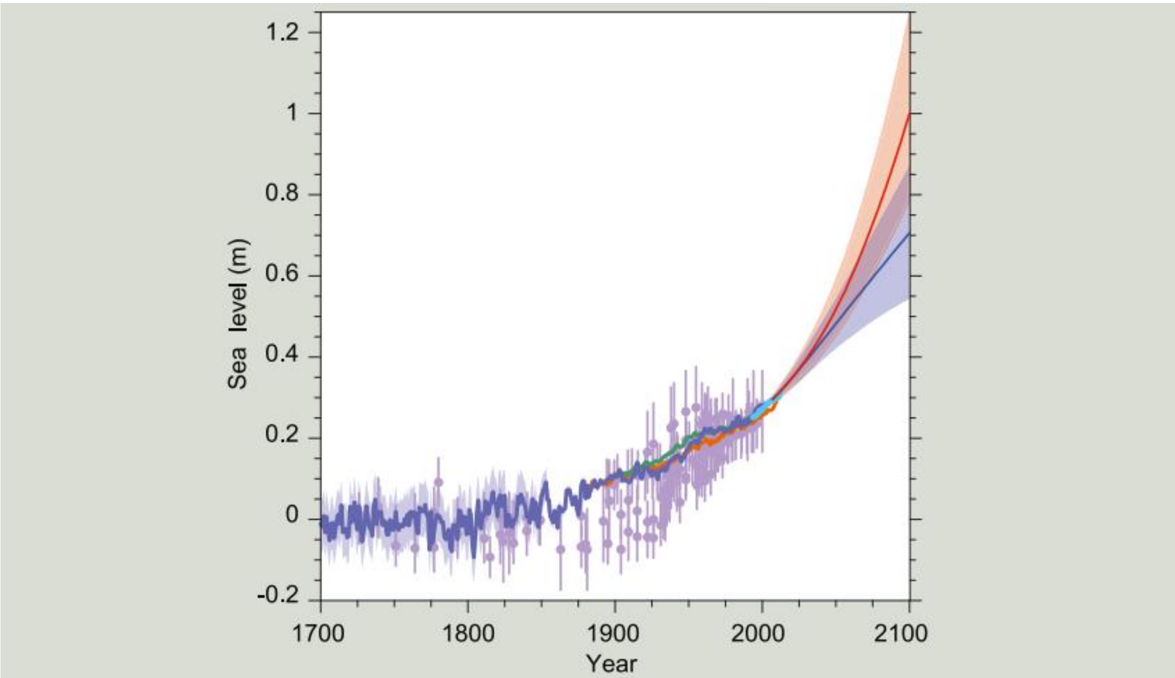
5. **Response to Instructions**

1. The dependence of the predicted sea level rise trajectories on emissions scenarios.

Australia, like other nations, is already experiencing sea level rise. Sea level varies from year to year and from place to place, partly due to the natural variability of the climate system from the effect of climate drivers such as El Niño and La Niña. However, the dominant contributors to on-going sea-level rise since the 1970s have been ocean thermal expansion, combined with ice loss from glaciers and the Greenland and Antarctic ice sheets. These factors are contributing to current sea-level rise at an increasing rate in response to ongoing global warming (IPCC, 2013). Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system resulting in continued increases in mean sea level. Limiting climate change and subsequent sea-level rise therefore requires substantial and sustained reductions of greenhouse gas emissions.

An emissions pathway is the trajectory of annual greenhouse gas emissions over time, while an emissions scenario is a description of how the future may unfold based on factors such as the socioeconomic situation and a description of the key driving forces and future changes in emissions, temperature, or other climate change-related variables (UNEP, 2021).

Therefore, future predictions of sea level rise are dependent on the assumed emissions scenario and emissions pathway adopted. An example of this is shown in Figure 2.



TFE.2, Figure 2 | Compilation of paleo sealevel data (purple), tide gauge data (blue, red and green), altimeter data (light blue) and central estimates and *likely* ranges for projections of global mean sea level rise from the combination of CMIP5 and process-based models for RCP2.6 (blue) and RCP8.5 (red) scenarios, all relative to pre-industrial values. {Figures 13.3, 13.11, 13.27}

Figure 2 Comparison of global mean sea level derived from various sources and projections of global mean level rise in the future for different assumed emissions scenarios (from IPCC, 2013)

There is considerable overlap in predicted emissions scenarios till mid-century (around 2050) due to past emissions, as shown in Figure 3, which means that many of the impacts of climate change are likely to be realised despite any future emissions reductions.

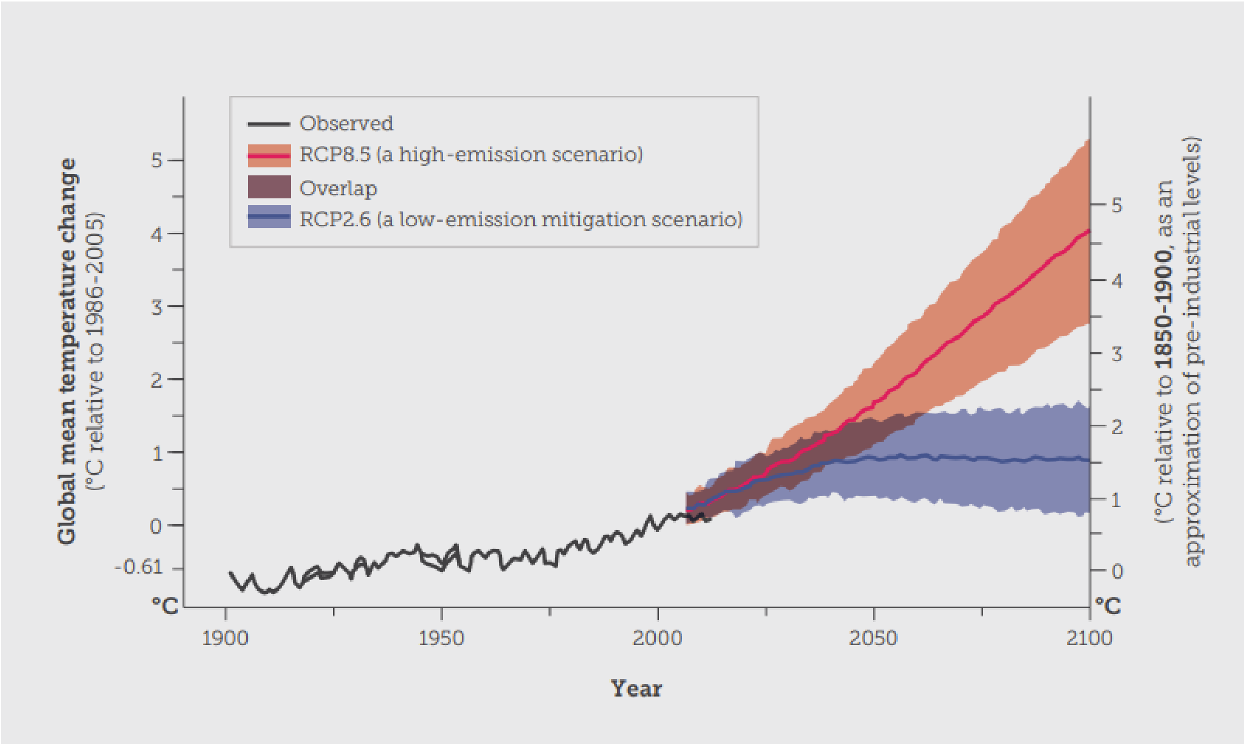


Figure 12: RCP emissions scenarios for different concentrations of carbon dioxide (CO_2) (IPCC 2014a). The upper bound (red, RCP8.5) is a business as usual CO_2 emissions pathway, while the lower bound (blue, RCP2.6) is a very swift reduction in CO_2 emissions, equivalent to a 1.5°C increase in temperature from pre-industrial levels. We are locked in to temperature rises until about 2050, but these paths diverge significantly depending on the climate action we take now. More pronounced extreme weather, including storms is predicted for the higher concentration CO_2 pathways.

Figure 3 A comparison of observed and future temperature predictions for different climate scenarios (from the Climate Council of Australia, 2016)

2. A description of the IPCC emissions scenarios including the SSP5-8.5 Low Confidence scenario.

The Special Report on Emission Scenarios (SRES) by IPCC (2000) outlines emissions scenarios that were developed by different modelling groups around the world to explore how the world might change over the coming century. They looked at four different possible future trajectories of population, economic growth, and greenhouse gas emissions. These scenarios were used in the IPCC third and fourth assessment reports (IPCC, 2001; and IPCC 2007). However, by the late 2000s these original scenarios were becoming outdated.

Researchers then developed the "Representative Concentration Pathways" (RCPs) which describe different levels of greenhouse gasses and other radiative forcings that might occur in the future. They developed four pathways, spanning a broad range of forcings at 2100 (2.6, 4.5, 6.0, and 8.5 watts per meter squared). Radiative forcing is a measure of the combined effect of greenhouse gases, aerosols, and other factors that can influence climate to trap additional heat. These scenarios were used in the IPCC fifth assessment report (IPCC, 2014).

When comparing SRES and RCP scenarios, SRES A1fI is like RCP 8.5; SRES A1B to RCP 6.0 and SRES B1 to RCP 4.5. The RCP 2.6 scenario is much lower than any SRES scenario because it includes the option of using policies to achieve net negative carbon dioxide emissions before end of century, while SRES scenarios do not (Figure 4).

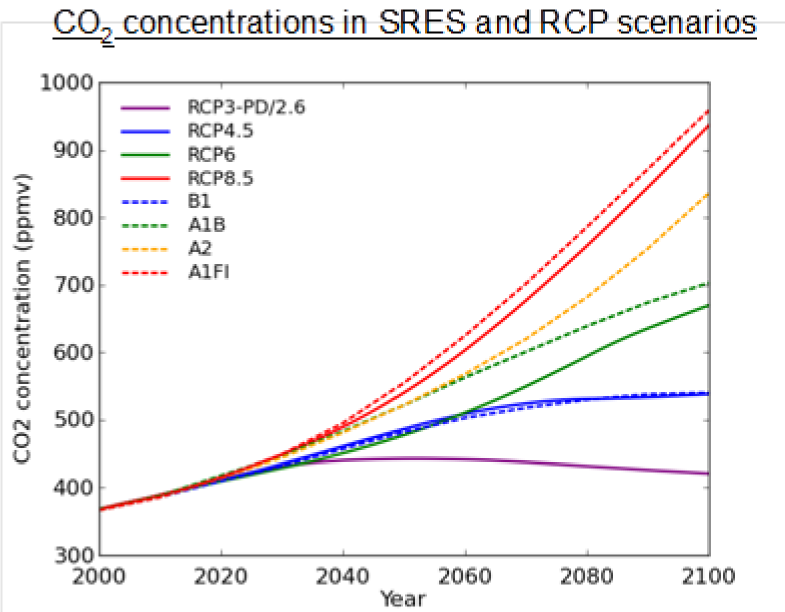


Figure 4 Comparison of climate emissions scenarios SRES and RCPs (from Climate Change in Australia, https://www.climatechangeinaustralia.gov.au/en/projections-tools/climate-futures-tool/experiments/)

In the IPCCs 6th Assessment Report (IPCC, 2021), the previous RCP scenarios have been combined with socio-economic factors and are called Shared Socioeconomic Pathways (SSPs), which describe the future emissions scenarios and things such as population, economic growth, education, urbanisation, and the rate of technological development. These SSPs are described below (IPCC, 2021; Meinshausen et al, 2020)[1]:

- SSP1-1.9 holds warming to approximately 1.5°C above 1850-1900 in 2100 and implies net zero CO2 emissions around the middle of the century (2050). It assumes relatively optimistic trends for human development in the context of driving the emissions trajectory downward, with substantial investments in education and health, rapid economic growth, and well-functioning institutions.
- SSP1-2.6 stays below 2.0°C warming relative to 1850-1900 (median) with implied net zero emissions in the second half of the century (after 2050). It assumes the same socioeconomic shifts towards sustainability as SSP1-1.9 but temperatures stabilise higher.
- SSP2-2.6 *low confidence* scenario incorporates a representation of the potential effect of low-likelihood high-impact ice sheet processes that cannot be ruled out.
- SSP2-4.5 scenario deviates mildly from a 'no-additional- climate-policy' (i.e., no new emissions reduction targets) reference scenario, resulting in a best-estimate warming around 2.7°C by the end of the 21st century relative to 1850-1900.

[1] Useful descriptions of the scenarios can be found at these sites:
https://www.reuters.com/business/environment/un-climate-reports-five-futures-decoded-2021-08-09/

- SSP3-7.0 assumes no additional climate policy (i.e., no new emission reduction targets) and high non-CO2 emissions. This scenario assumes emissions and temperatures rise steadily and CO2 emissions roughly double from current levels by 2100. Countries become more competitive with one another, shifting toward national security, and ensuring their own food supplies. By the end of the century, average temperatures have risen by 3.6°C.
- SSP5-8.5 assumes no additional climate policy and continued socioeconomic development which includes the use of fossil fuels. It is a high-end baseline scenario. However recent analysis (e.g., Schwalm et al, 2020) indicates that despite recent progress on reducing emissions, RCP8.5 (and its most recent iteration as SSP5-8.5) is a useful tool for quantifying climate risk especially over the near- to mid- term (mid-century). Schwalm et al (2020) found that "*Not only are the emissions consistent with RCP8.5 in close agreement with historical total cumulative CO_2 emissions (within 1%), but RCP8.5 is also the best match out to midcentury under current and stated policies with still highly plausible levels of CO_2 emissions in 2100*."
- SSP5-8.5 *low confidence* scenario incorporates a representation of the potential effect of low-likelihood, high-impact ice sheet processes that cannot be ruled out in addition to the effects of SSP5-8.5. This scenario represents the upper range of the modelled sea level rise predictions (termed a 'high end scenario') and reflects the reduced understanding of the physical processes controlling future mass loss from the Greenland ice-sheet and the Antarctic ice-sheet although this understanding has increased significantly since the IPCC 5th Assessment report.

The SSP5-8.5 scenario is similar to the original RCP8.5, though it features around 20% higher CO_2 emissions by the end of the century and lower emissions of other greenhouse gases.

The IPCC 6th Assessment Report (IPCC, 2021) Box TS.4 notes that "*under the higher CO_2 emissions scenarios, there is deep uncertainty in sea level projections for 2100 and beyond associated with the ice-sheet responses to warming. In a low-likelihood, high-impact storyline and a high CO_2 emissions scenario (essentially the SSP5-8.5 low confidence scenario), ice-sheet processes characterized by deep uncertainty could drive GMSL rise up to about 5 m by 2150. Given the long-term commitment, uncertainty in the timing of reaching different GMSL rise levels is an important consideration for adaptation planning*." This is summarised in the following figure from the same report.

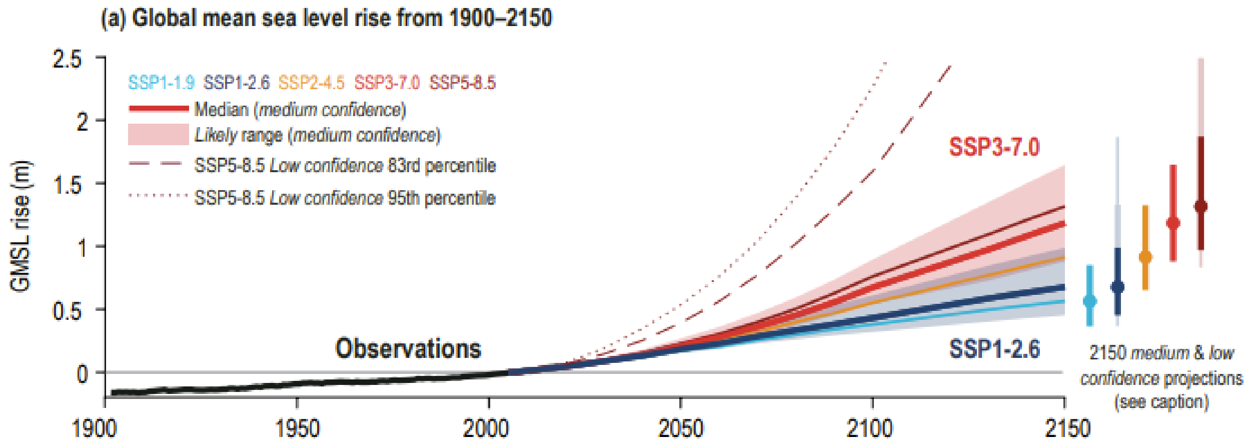


Figure 5 Global mean sea level change on different time scales and under different scenarios (from Box TS.4, IPCC 2021)

3. An overview of the United Nations Emissions Gap Report 2021 and what it means in terms of evidence of actual reduction in emissions.

The latest United Nations Emissions Gap Report (UNEP, 2021) provides an overview of the difference between predicted greenhouse emissions in 2030 assuming countries are successful in implementing their climate mitigation strategies/pledges, and what these pledges actually should be to avert the worst impacts of climate change by limiting global warming to well below 2°C and pursuing no more than 1.5°C (defined as the goal of the Paris Agreement; United Nations, 2015). This difference between where we will likely be and where we need to be is referred to as the 'emissions gap'.

Like the previous 11 iterations, the 2021 Emissions Gap Report was prepared by an international team of 78 leading scientists from 44 expert institutions across 24 countries, who assessed all available information, including that published in the context of the IPCC reports, as well as in other recent scientific studies. The analysis also considered the most recent mitigation pledges by different countries (UNFCCC, 2021).

The report shows that <u>neither</u> current policies <u>nor</u> the latest commitments and announced pledges across countries are consistent with limiting global warming to well below 2°C, or pursuing 1.5°C, compared to pre-industrial levels.

New or updated commitments and announced pledges were shown to have only limited impact on global emissions and the emissions gap in 2030, with further reductions in emissions by 30% needed to limit warming to 2°C and 55% is needed for 1.5°C. The authors predict that if this is continued throughout this century, "*it would result in warming of 2.7°C. <u>The achievement</u> of the net-zero pledges that an increasing number of countries are committing to would improve the situation, limiting warming to about 2.2°C by the end of the century*."

Figure 6 (from UNEP, 2021) provides a clear summary of the resultant global temperature increase for different emissions scenarios and the emissions gap in 2030, while Figure 7 presents the greenhouse gas emissions by country together with an indication of the level of per capita emissions consistent with 2°C and 1.5°C scenarios by 2050. **The gap between what is required and what has been proposed is significant**.

Note that the term NDC is used to describe each countries national efforts to reach the Paris Agreement's long-term temperature goal of limiting warming to well below 2°C and stands for Nationally Determined Contribution. These are contingent on a range of possible conditions. The figures reproduced here do not include the additional emissions reduction targets for Australia detailed in the recent Climate Change Bill 2022.

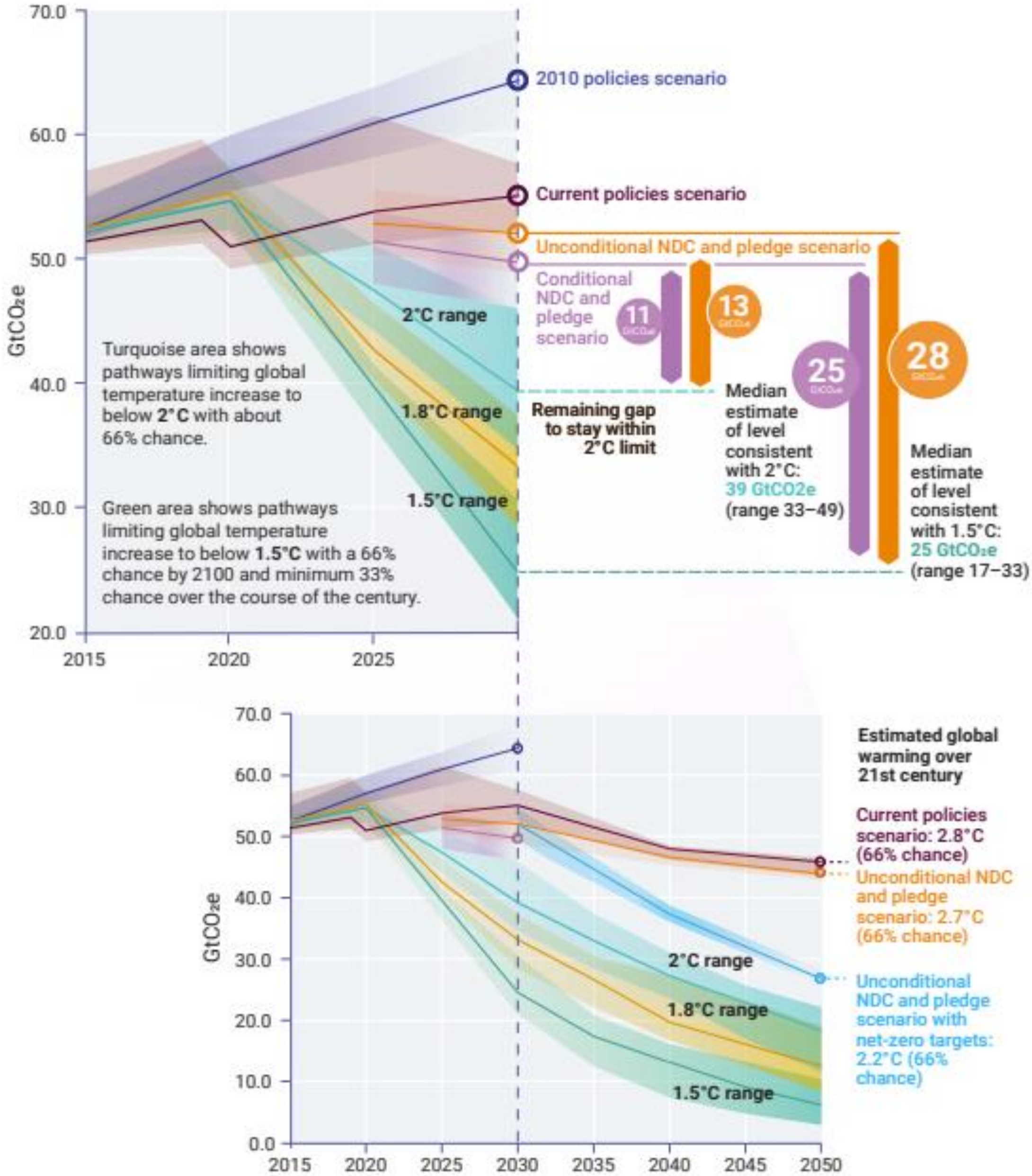
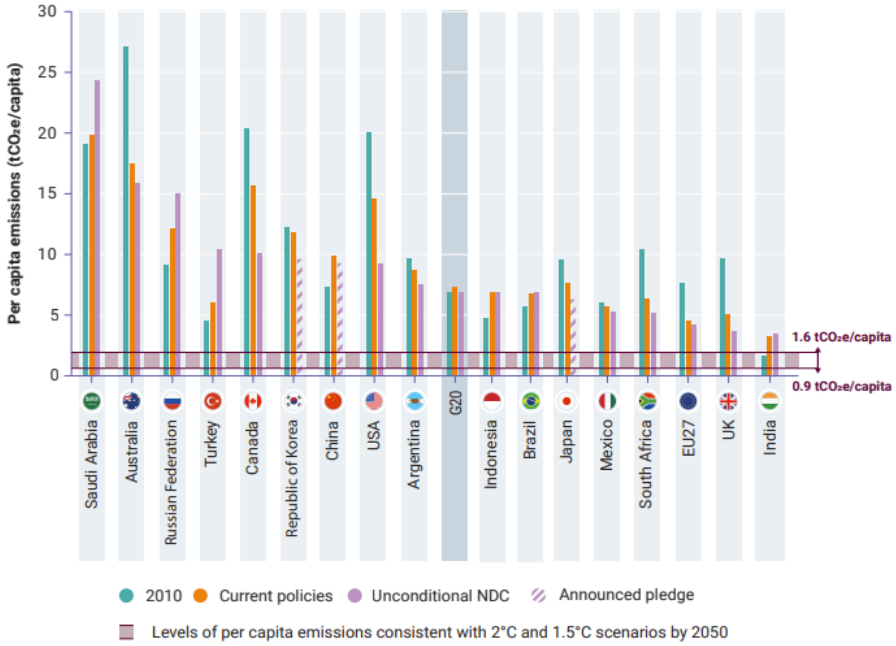


Figure 6 Global greenhouse gas emissions under different scenarios and the emissions gap in 2030 (medium estimate and tenth to ninetieth range (Figure ES.6, from UNEP, 2021)



Notes: i) Figures include LULUCF. ii) Central estimates are a median value when five or more studies were available, otherwise they are average values. iii) Data on historical and projected (medium fertility variant) population per country are taken from the 2019 Revision of World Population Prospects (United Nations Department of Economics and Social Affairs [UN DESA], Population Division 2019). iv) The figures presented here may not exactly match official data due to the differences in data sources. v) G20 members are sorted in decreasing order of NDC emissions projections. vi) To estimate G20 total emissions for the NDC and announced 2030 pledges scenario, emissions projections under the current policies scenario were used for India, the Russian Federation and Turkey.

Figure 7 Per capita greenhouse gas emissions of the G20 and its individual members by 2030 under nationally determined contributions and other announced 2030 pledges as at 30 September 2021 (Figure 2.6 from UNEP, 2021)

What the results shown in these figures mean is that the gap between current and future emissions rates and targets is large and therefore an increase in global mean temperature of above 2°C by 2050 will likely occur.

4. Victoria's adoption of the SSP8.5 scenario in Coastal Policy.

The 2008 Victorian Coastal Strategy focussed on climate change as one of three significant issues that required specific attention. **Based on the IPCC 4th Assessment Report (IPCC, 2007), it stated that a "policy of planning for sea level rise of not less than 0.8 metres by 2100 should be implemented" which is based on the upper bound of the projections, although not stated explicitly is aligned with the SRES A1F1 scenario**.

The Victorian Coastal Council commissioned a report, Derivation of Victorian Sea Level Planning Allowances (Hunter, 2013) to provide an update of sea level rise projections as they relate to the coast of Victoria for the 2014 Victorian Coastal Strategy (VCS). The report derived estimates of planning allowances for sea level rise along the Victorian coastal based on the IPCC 4th Assessment report (IPCC, 2007) SRES A1F1 scenario.

The sea level allowance was derived in the following format (Church et al, 2016):

$$A = \Delta z + \sigma^2/2\lambda$$

where Δz is the mean sea-level rise for a given scenario and future time period, σ^2 is derived from the 5-95% range of the modelled sea-level rise projections and λ is the scale parameter that describes the slope of the extreme sea level return period curve (either based on tidal gauge analysis or model studies such as Haigh et al, 2014).

The VCS also provided the direction such that:

- Plan for sea level rise of not less than 0.8 m by 2100, and allow for the combined effects of tides, storm surges, coastal processes and local conditions when assessing risks and impacts.
- Apply the precautionary principle to planning and management decision-making when considering the risks associated with climate change.

This is reiterated in the Victorian Marine and Coastal Policy (2020) which states:

If there are threats of serious or irreversible environmental or other damage, lack of full scientific certainty should not be used as a reason for postponing cost-effective precautionary measures to prevent environmental or other degradation

The work by Hunter (2014) recalculated the level rise allowances for Victoria based on the IPCC 5th Assessment report projections (IPCC, 2013), using the emissions scenario RCP8.5. The revised allowances were similar to those derived from the previous projections.

Important assumptions within the derivation of the sea level allowances were that:

- ***The variability of the storm tides will not change in time***. Hunter (2013, 2014) state that this information was supported by previous studies. More recent studies (e.g., Wood et al, 2022) are showing potential increase to "storminess" - the frequency of extreme surge events - with climate change due to increased storm activity in some areas. Relevant to the Victorian coast, are the frequency of East Coast Lows (ECLs). Several studies indicate a decline in the frequency of ECLs but with an increase in severity (see Di Luca et al for a summary) but there is still considerable uncertainty in these predictions due to the inability of the models to accurately resolve, detect and track these storm systems.

  What was also not considered at the time was the potential for complex risks resulting from multiple climate hazards occurring concurrently, and interacting, compounding the overall risk (IPCC, 2022) such as where there is the interaction between coastal and catchment flooding. **IPCC (2022) notes that "*Future sea level rise combined with storm surge and heavy rainfall will increase compound flood risks (high confidence)*"**.

- ***No contribution due to possible changes in wave setup or runup***, which is consistent with current recommended coastal flood modelling approaches. However, a recent paper by Melet et al. (2020) summarises current research on potential changes in wave setup under future sea level scenarios. Projected changes in wave setup were a combination of projected changes in wind-wave-induced setup and of swell-induced setup. They found limited changes at a global scale, but at a regional or local scale, wave setup changes over the next 30 to 80 years are not negligible. Potential changes to wave setup because of sea level rise could be considered in future detailed coastal modelling studies should suitable methodologies for predicting these changes become available or an additional allowance for such changes could be included for planning purposes.

- ***No contribution due to the change in tides caused by sea-level rise***. Hunter (2013 and 2014) stated that evidence at the time suggested that changes to tides are generally small with sea level rise, however more recent work (e.g., Dominicis et al, 2020; Khojasteh et al 2021) is indicating, particularly in delta, estuary, and coastal lagoon environments, that feedback or amplification of tides and surges may occur with sea level rise which can increase extreme water levels. A further allowance for potential changes to tides and tidal amplification may be warranted in these environments.

- ***Is dependent on the distribution of uncertainty in the sea level rise projections***. In the absence of an agreed distribution for the projections the authors have based their analysis on a normal distribution, which they note " *represent a practical solution to planning for sea-level rise while preserving an acceptable level of flooding likelihood, in cases where 'getting the allowance wrong' is manageable. However, in cases where the consequence of flooding would be 'dire' (in the sense that the consequence of flooding would be unbearable, no matter how low the likelihood, as in the case of the Netherlands), a precautionary approach is to choose an allowance based on the best estimate of the maximum possible rise.*" This comment reiterates the idea that locally specific risk factors should be considered when setting the sea level rise allowance for planning purposes.

  In recent years there has been increasing interest in 'high end sea-level scenarios (HES)' (e.g., Dayan et al, 2021) as the large uncertainties of ice sheet melting processes bring in a range of unlikely, but not impossible, future outcomes. In these scenarios the upper 'tails' of the distribution of uncertainty are different to say a normal distribution and are increasingly of interest to risk-adverse stakeholders such as those managing critical coastal infrastructure. Figure 8 from Dayan et al (2021) presents a summary of the HES results from different studies for both low emission (RCP2.6) and high emission (RCP8.5) scenarios. These results show the plausibility of realising global sea level rise of between 0.82m to 1.69m by the year 2100 even under a low emissions scenario.

Emission scenario	Low ~ RCP2.6						High ~ RCP8.5					
Global HESs (m)	HESs-A (83rd percentile)			HESs-B (95th percentile)			HESs-A (83rd percentile)			HESs-B (95th percentile)		
Year Authors	2050	2100	2200	2050	2100	2200	2050	2100	2200	2050	2100	2200
Present work	0.44	1.06	2.41	0.73	1.69	3.98	0.54	1.91	4.45	0.84	3.22	11.15
Bamber et al., 2019	0.40	0.98	–	0.49	1.26	–	0.47	1.74	–	0.61	2.38	–
Kopp et al., 2017	0.33	0.78	1.61	0.41	0.98	2.06	0.40	2.09	8.96	0.48	2.43	9.62
Le Bars et al., 2017	–	–	–	–	–	–	–	2.38*	–	–	2.92	–
Jackson and Jevrejeva, 2016	–	–	–	–	–	–	–	0.98	–	–	1.18	–
Grinsted et al., 2015	–	–	–	–	–	–	–	1.20	–	–	1.83	–
Kopp et al., 2014	0.29	0.65	1.60	0.33	0.82	2.40	0.34	1.00	2.80	0.38	1.21	3.70

*No value is given when it has not been directly provided in the publications. Red boxes display the highest GMSL values, while orange boxes indicate when the GMSL value is higher than ours.*Actually, Le Bars et al. (2017) only provide the 80th percentile of the probability density function.*

Figure 8 Global HESs (m) as provided in recent publications (from Dayan et al, 2021)

Most recently, the Marine and Coastal Policy (March 2020) notes that:

The latest projections from the Intergovernmental Panel on Climate Change on global sea level rise are for an increase of between 0.61 and 1.10 metres by 2100 above 1986-2005 levels under a high-emissions scenario[2], with a global average of 0.84 metres. The range of possibilities requires us to prepare to be adaptable and flexible, and to respond to new information and observed changes in the physical environment.

With regards to flood modelling, the Australian Rainfall and Runoff Guidelines, Book 1 Chapter 6 (Ball et al, 2019) discusses consideration of climate change in relation to flood modelling. The guide has adopted the IPPC Fifth Assessment Report (IPCC, 2013) and recommends the use of RCPs 4.5 and 8.5 for assessing the impacts of climate change.

5. The rate of local sea level rise as recorded by the Portland tide gauge.

Monthly mean sea levels (MSLs) are reported for tide gauges around Australia by the Bureau of Meteorology (BoM). Victorian gauges include Portland, Lorne, and Stony Point. The monthly mean sea level data for Portland are shown in Figure 9 along with linear trend lines. The data clearly shows a gradual increase in mean sea level at Portland since 1982. The Portland tide gauge is the most relevant tide gauge for monitoring sea levels for coastal communities in the Port Fairy region and is used by the BoM to provide informal storm tide flood watch alerts to GHCMA and Moyne Shire Council for Port Fairy and Warrnambool and in the future more formal warnings through the new Severe Weather Warning for Damaging Surf which was launched for Victoria on 30 June 2022.

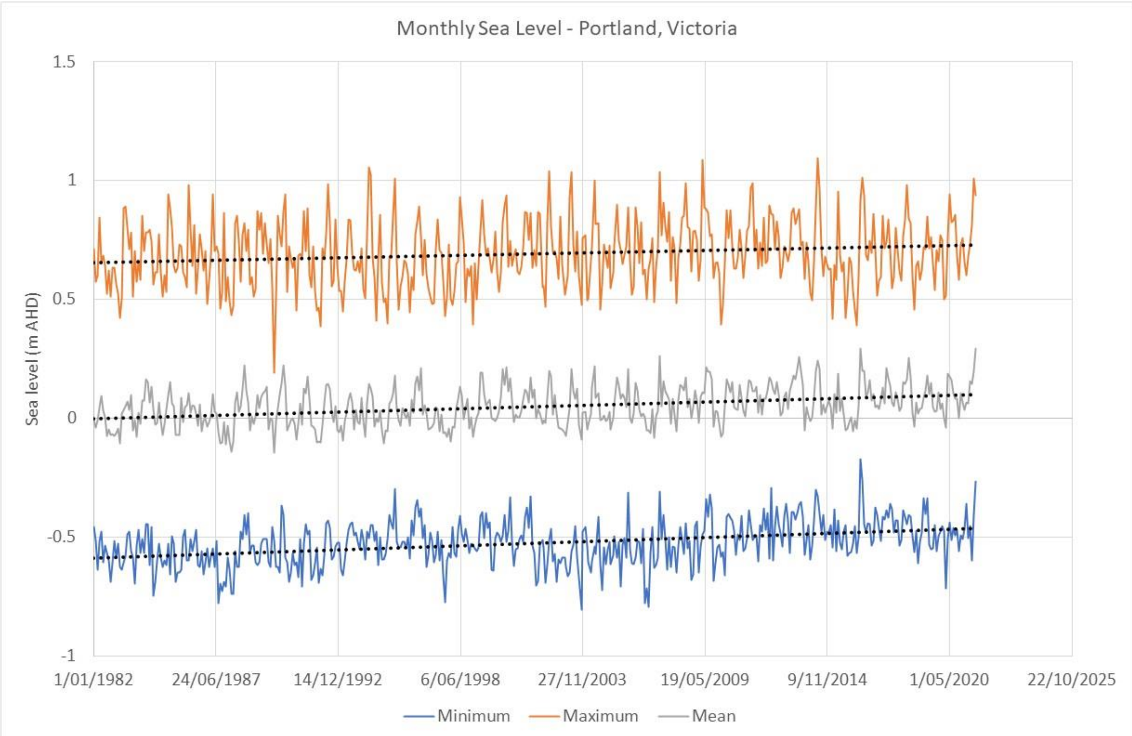


Figure 9 Monthly mean sea level data at Portland, Victoria (linear trend lines shown in black)

[2] The high emissions scenario refers to SSP5-8.5

Monthly short-term sea-level rise (SLR) trend reports (rate of movement in mm/year) are also provided by the BoM for the Portland tide gauge. The overall rates of movement are updated every month by calculating the linear slope during the tidal analysis of all the data available at the tide gauge. Longer term trends can also be analysed and the average trend since 2000 at the Portland gauge is a rate of movement of 3.4 mm/year which is consistent with the predicted rate of movement across all the SSP emissions scenarios presented in IPCC (2021).

Any local sea level projections should be added to the local mean sea level. This 'grounds' the future sea level to a vertical datum of the locality. As sea level rises, the average measured MSL at the local gauge station can be tracked relative to the recommended baseline MSL value. This can be done by analysing recent annual MSL from the gauge data or as reported on the BoM website. For Port Fairy, the data for Portland can be tracked on a monthly or annual basis and compared to the selected emissions scenario. In this way, the local change in sea level can be readily monitored and linked to predicted time frames associated with signals, triggers, and thresholds in any adaptation pathway.

6. Projected timeframes to reach 0.8 and 1.2m sea level rise based on analysis of the Portland Tide Gauge data and predicted emissions scenarios.

The Sea Level Rise Projection Tool (https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool) presents the projections for these IPCC 6th Assessment scenarios at all tide gauge stations in the analysis including Portland, Lorne, and Stony Point.

A comparison of the measured rate of sea level movement at Portland with the predicted rates in 2020 from the IPCC 6th Assessment analysis are presented in Table 1. As well as the median value, the 5th and 95th percentiles are also included. These represent the low and high extreme values for each scenario. The measured rate of sea level movement is highlighted, and shows it is within the range of the predicted values (5th to 95th percentiles).

Table 1 Rates of sea level movement from IPCC 6th Assessment scenarios predicted in 2020 for Portland compared to averaged measured rates at Portland (5th, 50th and 95th percentile values)

Scenario	Rate of movement (mm/year) for given percentile		
	5th	50th	95th
SSP1.9	2.1	4.1	7
SSP2.6	2.1	3.8	6.5
SSP4.5	1.9	3.8	6.6
SSP8.5	2.0	4.4	7.4
SSP2.6 *(low confidence)*	2.0	4.0	9.3
SSP8.5 *(low confidence)*	1.7	4.5	11.6
Measured rate of movement (Portland)	2.1	3.1	5.4

The predicted time at which different SLR thresholds are predicted to be reached is summarised in Table 2 and Table 3 for the 50th and 95th percentile predictions, with SSP5-8.5 highlighted.

Table 2 Summary of year at which the sea level rise (50th percentile prediction) threshold values are reached for different IPCC 6th Assessment scenarios. Only predictions up to 2150 are included.

Scenario	Time when sea level rise threshold is reached (50% percentile prediction)						
	0.2 m	0.4 m	0.8 m	1.2 m	1.6 m	2.0 m	2.4 m
SSP1-1.9	2055	2103	-	-	-	-	-
SSP1-2.6	2052	2095	-	-	-	-	-
SSP2-4.5	2051	2081	2135	-	-	-	-
SSP3-7.0	2050	2073	2116	2145	-	-	-
SSP5-8.5	2045	2066	2107	2147	-	-	-
SSP5-8.5 *(low confidence)*	2048	2062	2095	2121	2139	-	-

Table 3 Summary of year at which the sea level rise (95th percentile prediction) threshold values are reached for different IPCC 6th Assessment scenarios. Only predictions up to 2150 are included.

Scenario	Time when sea level rise threshold is reached (95% percentile prediction)						
	0.2 m	0.4 m	0.8 m	1.2 m	1.6 m	2.0 m	2.4 m
SSP1-1.9	2036	2060	2102	-	-	-	-
SSP1-2.6	2036	2057	2092	2118	-	-	-
SSP2-4.5	2037	2054	2086	2118	2150	-	-
SSP3-7.0	2039	2053	2085	2105	2128	-	-
SSP5-8.5	2033	2053	2080	2098	2117	2136	-
SSP5-8.5 *(low confidence)*	2030	2046	2062	2075	2085	2095	2103

Where the time to reach the sea level rise threshold is beyond 2150 the predictions have not been provided in the NASA prediction tool. This likely reflects the high level of uncertainty associated with climate modelling beyond this timeframe. Sea level rise of 2.0 m or more is only predicted before 2150 under the SSP5-8.5 at the 95th percentile and SSP5-8.5 *low confidence* scenarios at the 83rd percentile and above.

A key difference between these scenarios is the significantly reduced timeframes for reaching sea level rise thresholds. For example, attainment of the level of risk posed by 1.2 m increase in mean sea level could be realised 23 years earlier under the SSP5-8.5 *low confidence* scenario compared to the SSP5-8.5 scenario. It is also important to note that the projections for the HES (discussed in Response #4 and as indicated by the 95th percentile scenario results in Table 3) follow similar trajectories across all the different scenarios. For example, 0.8m sea level rise is predicted to occur within a 22 year window from 2080 to 2102 (not including the low confidence scenario), with a similar range for 1.2m sea level rise (2098 to 2118).

7. Projected operable lifespan of the proposed controls.

The C69 Amendment proposes to introduce a Land Subject to Inundation Overlay and Floodway Overlay to the Port Fairy Township to identify areas subject to coastal inundation and a 1.2 m sea level rise. These overlays are based on work detailed in Cardno (2019) and HARC (2021). The associated controls within the Port Fairy Floodplain Development Plan include the recommended minimum flood level (Nominal Flood Protection Level, NFPL) based on the 1% AEP flood level for the 1.2m mean sea level rise scenario with no added freeboard. Analysis of levels undertaken by the CMA has shown that floors built to this level will in general, result in floor levels for new development in Port Fairy being raised in the order of 100mm above the minimum floor level the CMA is currently recommending for new development. This level is currently the estimated 1%AEP flood level accounting for 0.8m of sea level rise, plus an added freeboard of 600mm. (Glenelg Hopkins CMA, 2021: Floor Level Analysis).

A 1.2m increase in sea level can be expected at Portland (and Port Fairy) by around 2098 (Table 4 below). At this point in time, buildings with floors finished at the 1%AEP flood level that accounts for 1.2 m sea level rise as proposed via Moyne C69 will no longer have <u>any</u> margin of safety above 1% AEP floods. To maintain a reasonable safety margin (0.6m -which is the current minimum required at Port Fairy), it would be appropriate to begin adding a freeboard margin to this flood level estimate well prior to actual attainment of this sea level rise impact threshold. This decision point is termed a trigger point within an adaptation pathways approach (see Figure 10 below).

Table 4 Indicative adaptation thresholds and triggers under SSP5-8.5 (IPCC 6th Assessment Scenarios) – Port Fairy

Adaptation threshold (rel. sea level)	Threshold likely to be reached by (95th percentile, SSP5 8.5)	Time NFPL is effectively reduced to 0.6 m	Mean Sea Level NFPL trigger at Portland (TGZ)	Mean Sea Level NFPL trigger at Portland (m AHD)
1.2	2098	2068	1.17	0.66

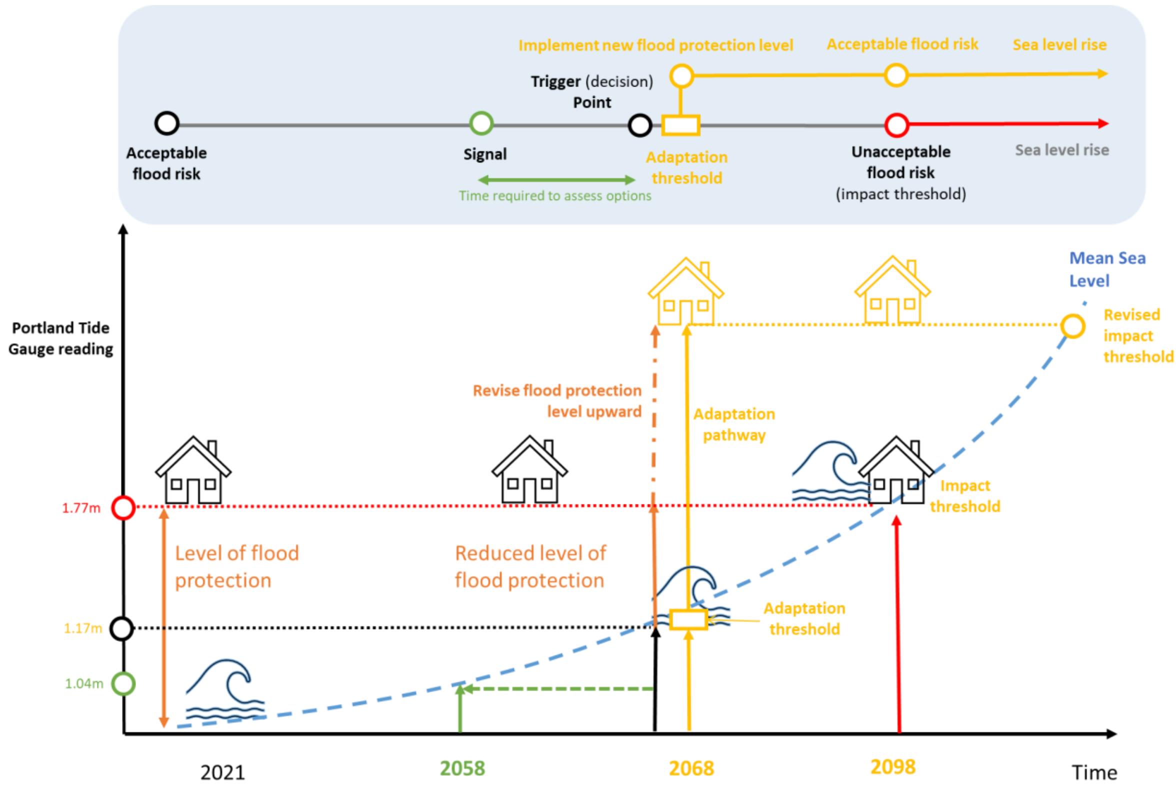


Figure 10 Port Fairy example of applying a flood-level based adaptation pathway

Via the analysis I undertook and documented in Streamology (2022), the best available information shows that an appropriate trigger for initiation of the NFPL resetting process (i.e., adding a freeboard margin to the adopted 1% AEP flood level accounting for 1.2m of sea level rise) is likely to be when the Portland tide gauge shows an average tide gauge reading of 1.17 m. Using the SSP5-8.5 emissions scenario sea level rise trajectory data, attainment of this level at the Portland tide gauge can be expected to occur at by around the year 2068

To minimise exposure of new development to this risk, and to facilitate adaption (where possible) of existing development, the freeboard margin must be reset well prior (say 10 years) to the NFPL threshold being met (the time when the adopted NFPL would no longer provide any freeboard margin). This is termed an early warning "signal" in the adaptation pathway, where activities required to inform the future trigger point should commence.

An early warning signal of 10 years prior is suggested for resetting NFPLs. This allows time for funding to be identified and completion of any technical studies required as a basis for the next step in the adaptation process. At Port Fairy this would be around 2058, when sea level rise of around 0.47 m could have occurred (Figure 10 above).

This means that the best estimate of the time over which the 1.2m sea level rise flood level based NFPL is an appropriate planning control is about 36 years. After this time (according to the current best available information) the performance of the adopted NFPL in minimising flood risk will decline to a freeboard margin of less than 0.6 metres and upward revision will be required, potentially in addition to consideration of the need to increase the extent of the flood overlays using new flood risk mapping that accounts for sea level rise in excess of 1.2m.

8. Validity of the CMAs proposed approach to the NFPL.

Development of a pathway approach to the setting and revision of the NFPL applied in coastal development decisions will clarify the way forward with building floor levels for all stakeholders and help the region stay ahead of a worsening coastal flood risk profile. This pathways approach concept is summarised previously in the background section of this report and is detailed in Streamology (2022).

The first step in establishing a pathway approach is selection of an appropriate NFPL. The approach for Port Fairy has been to adopt a design 1% AEP flood level estimate from one of the modelled future sea level scenario increments (Cardno, 2019; HARC, 2021) with no freeboard margin. As mentioned above, this is because of the increase in elevation represented by each successive scenario. i.e., use of a future (projected) 1% AEP flood level estimate provides a degree of freeboard by nature of it simply being a higher level than the present day or near-term 1% AEP flood level estimates

Which flood level estimate is appropriate for adoption as the NFPL depends on how well a flood level estimate for a future sea level rise scenario balances the burden on development in the short term, with the avoidance of impacts and damage costs in the longer term. This approach to setting the NFPL differs from the common approach applied in the Glenelg Hopkins Region which has been to apply a minimum freeboard margin to adopted 1% AEP design flood level estimates. The difference is subtle in that a freeboard margin is built into a NFPL set using a projected (future) 1% AEP flood level estimate with no added freeboard.

The GHCMA adaptation pathways approach logic and approach for monitoring and (in future) re-evaluating the NFPL is consistent with the risk management processes, outlined in AS 5334-2013 *Climate change adaptation for settlements and infrastructure - a risk based approach.* It builds and which builds in active monitoring and periodic reassessment of flood risks to address the considerable uncertainty in the estimated time frame over which the proposed NFPL is appropriate. It is also consistent with the risk management planning logic outlined by Hunter (2013).

Based on the HARC (2021) report, the difference in the maximum flood level at Belfast Lough and Bank Street for the 0.8m SLR and 1.2m SLR scenarios varied by around 0.6 to 0.7m. So, in effect the NFPL defined either for a 0.8m SLR scenario using the common approach or the proposed 1.2m SLR plus no freeboard are similar (the 0.8m SLR scenario is around 0.1m lower). Based on the logic described in Response #7, the NFPL based on the 0.8m SLR scenario with 0.6m freeboard would be an appropriate planning control for about 30 years. **The proposed NFPL is a pragmatic approach that recognises the future flood risks but doesn't impose onerous restrictions on redevelopment proposed for existing development**.

The flood extent for the higher sea level scenario is greater and therefore more properties will be subject to a flood risk consideration and the application of the NFPL within the proposed overlays, for a period potentially in the order of 36 years. If the 0.8m SLR scenario flood extent was instead used as the basis of the flood overlay those properties between the 0.8m SLR scenario flood extent and 1.2m SLR scenario flood extent would not be subject to the NFPL when setting minimum floor levels. These properties therefore may only have a freeboard above ground of 0.6m above 1% AEP flood levels until 0.2m SLR has occurred (approximately 2032). If the rate of sea level rise exceeds the SSP5-8.5 projection, then these properties will be at further increased risk from flooding. In addition, the inclusion of additional properties within the 1.2m SLR scenario flood event provides for consideration of the uncertainty in predicting rates of sea level change (Figure 2) and of the compounding risks associated with climate change on both coastal and catchment flooding (IPCC, 2022), and follows the precautionary approach to managing the flood risk between the 0.8m and 1.2m SLR thresholds.

The Insurance Council of Australia released a report in May 2022 which synthesised work on flood risk from a cost perspective. Top takeaways within the report which support the proposed NFPL approach include:

- Land use planning must consider flood risk beyond the 1% AEP event as well as projected changes to flooding driven by climate change,
- New developments must adhere to existing provisions in the floodplain handbook and consider the consequence and likelihood of the full range of possible flood events, including larger and rarer floods beyond the 100-year (1% AEP). This assessment should also consider future climate projections expected over the full lifecycle of the building.

A property built today can be expected to have a usable life of 30 to 50 years (e.g., Housing Design Standards 2018, Department of Health and Human Services, Victoria) however, many residential buildings across Victoria are currently older than this. Therefore, by incorporating a greater flood extent within the overlay, changes to sea level over the next 30-50 years can be accommodated and the increasing risk to the properties in the overlay can be effectively managed. This also aligns with the proposed monitoring and adaptation approach (Response #9 below).

Overall, the pathway approach to the setting and revision of the NFPL applied in coastal development decisions by the CMA is valid and provides improves certainty around the requirements to management flood risk at Port Fairy through the NFPL and the time frames over which NFPLs are likely to appropriate.

9. Outline of the logic for the CMAs proposed approach to increase the NFPL in concert with locally observed change in mean sea level as recorded by the Portland Tide Gauge.

Coastal flood risk management requires complex planning judgements to be made in terms of the timeframe over which land might be beneficially used and developed before the benefits of use and development are outweighed by the risks associated with flooding. Making these judgements is very challenging given the inherent uncertainty in the rate of sea level rise and the likely timing of sea level rise impacts. But what is certain is that sea level will continue to rise for centuries (or more), and the adequacy of NFPL conditions placed on development today will diminish into the future to the point where they are no longer adequate, so a set and forget approach to land use and development conditions is not a viable long-term option.

The CMAs proposed approach of linking future increases to the NFPL to measured changes in sea level aims to establish a clear framework for decision making that fully accounts for the wide range of plausible impact trajectories in concert with local observation of change. The Portland tide gauge provides a very useful local reference for measuring actual sea level rise which can be clearly tracked against projected changes. Tracking annual mean sea level trend data is the main way to evaluate whether actual change is tracking within the projected range or if sea level locally is changing slower or faster than both global rates and the projected local rates.

This aligns with Action 4 Adapt to the Impacts of Climate Change in the Draft Marine and Coastal Strategy (DELWP, 2021) which sets out actions to "review the planning benchmarks for rises in sea level based on the latest and best available science (IPCC reports)" and to "establish a process for future reviews of planning benchmarks so that they are aligned with the findings of future IPCC reports and assessments."

Figure 11 provides an example tracking chart for the Portland tide gauge. The 2020 mean sea level is presented compared to baseline for the Portland tide gauge (0.023 m relative change to the baseline value of 0.059 m AHD, 0.566 m TGZ). The baseline value relates to the sea level rise projections, which are referenced to a specific baseline period, and differ depending on when the projections were published. The IPCC 6th Assessment Report uses a baseline averaged over the

1995 to 2014 period and this is proposed to be adopted as the baseline for future tracking of sea level rise at the Portland gauge.

In further support of the adaptation pathways approach to the proposed NFPL control, the IPCC 6th Assessment Report (IPCC, 2022) provides the following commentary:

C.2.8 *Sea level rise poses a distinctive and severe adaptation challenge as it implies dealing with slow onset changes and increased frequency and magnitude of extreme sea level events which will escalate in the coming decades (high confidence). Such adaptation challenges would occur much earlier under high rates of sea level rise, in particular if low-likelihood, high impact outcomes associated with collapsing ice sheets occur (high confidence). Responses to ongoing sea level rise and land subsidence in low-lying coastal cities and settlements and small islands include protection, accommodation, advance and planned relocation (high confidence). These responses are more effective if combined and/or sequenced, planned well ahead, aligned with sociocultural values and development priorities, and underpinned by inclusive community engagement processes (high confidence).*

D1.1 *There is a rapidly narrowing window of opportunity to enable climate resilient development. Multiple climate resilient development pathways are still possible by which communities, the private sector, governments, nations and the world can pursue climate resilient development …… Climate resilient development pathways are progressively constrained by every increment of warming, in particular beyond 1.5°C…..*

D2.1 *Pathways towards climate resilient development overcome jurisdictional and organizational barriers, and are founded on societal choices that accelerate and deepen key system transitions. Planning processes and decision analysis tools can help identify low regrets options that enable mitigation and adaptation in the face of change, complexity, deep uncertainty and divergent views*

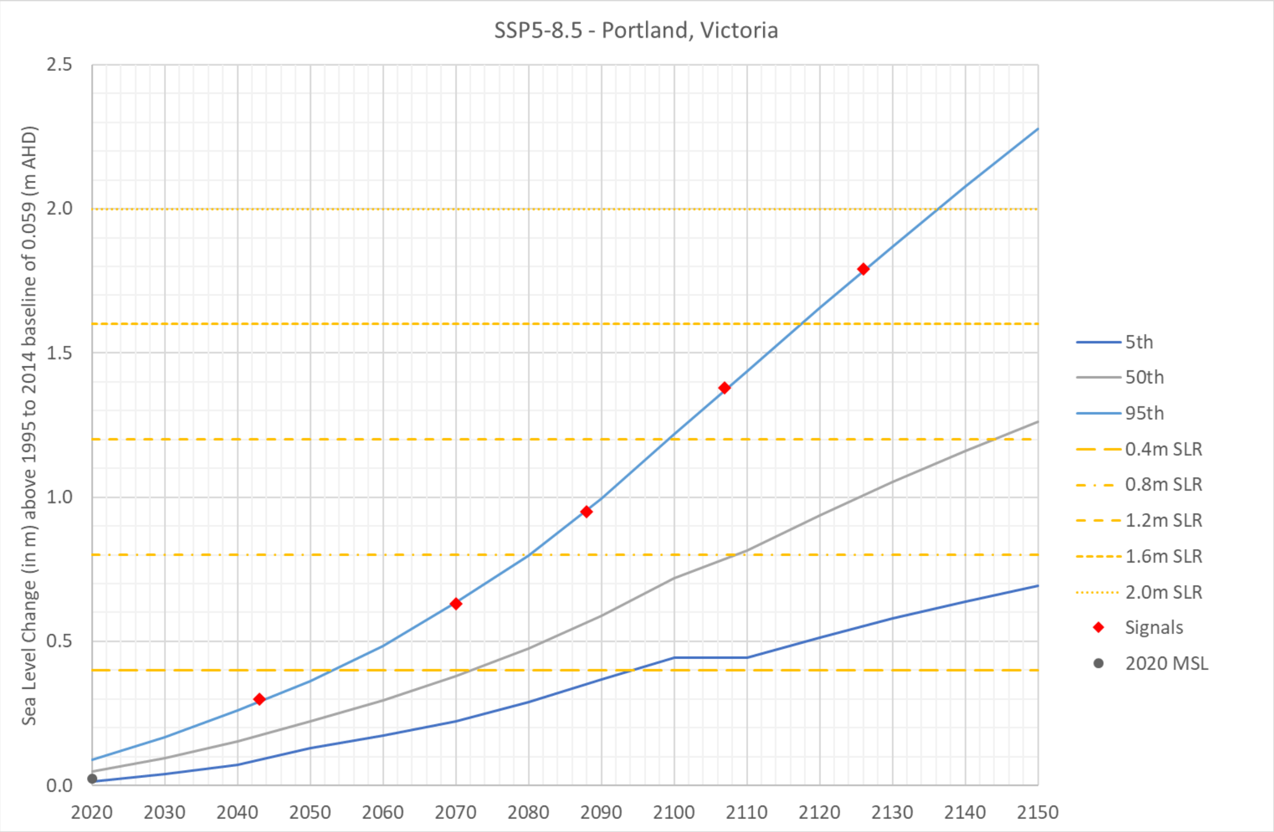


Figure 11 Projected sea level rise at Portland under emissions scenario SSP5-8.5 along with measured mean sea level in 2020 (from Streamology, 2022)

6. **Findings and Conclusions**

Based on my review and response to instructions, it is my opinion that:

1. Predicted sea level rise trajectories are dependent on the emissions scenario selected. However, there is considerable overlap between low and high emissions scenario trajectories to mid-century (around 2150) because of past emissions and **therefore adherence to the precautionary principle in adaptation planning is warranted**.
2. There have been several iterations of the IPCC emissions scenarios, although across all iterations a range of assumed future emissions assumptions from high to low ranges have been assessed. SSP5-8.5 is the high emissions scenario from the IPCC 6th Assessment report (IPCC, 2021), and it similar to the previously assessed scenarios RCP8.5 (IPCC, 2013) and A1F1 (IPCC, 2007). This scenario is a useful tool for quantifying climate risk especially over the near- to mid- term (mid-century) where many of the scenarios overlap. Schwalm et al (2020) found that "Not only are the emissions consistent with RCP8.5 in close agreement with historical total cumulative CO2 emissions (within 1%), but RCP8.5 is also the best match out to mid-century under current and stated policies with still highly plausible levels of CO2 emissions in 2100. **Therefore, planning measures based around an adaptation framework accounting for SSP5-8.5 are justified**.
3. The United Nations Emissions Gap Report 2021 provides an overview of the difference between predicted greenhouse emissions in 2030 assuming countries implement their climate mitigation strategies, and what these strategies actually need to be to avert the worst impacts of climate change by limiting global warming to well below 2°C and pursuing 1.5°C (defined as the goal of the Paris Agreement; United Nations, 2015). This difference between where we will likely be and where we need to be is referred to as the 'emissions gap'. The results of the analysis presented show that there is a significant emissions gap and that neither current policies nor the latest commitments and announced pledges by countries across the world are consistent with limiting global warming to well below 2°C, or pursuing 1.5°C, compared to pre-industrial levels. **What this means is that the gap between current and future emissions rates and targets is large and therefore an increase in global mean temperature of above 2^{o}C by 2050 will likely occur**.
4. Victoria's adoption of the RCP8.8 and now SSP8.5 scenario in Coastal Policy is a consistent position since the 2008 Victorian Coastal Strategy was released and applies the precautionary principle to planning and management decision-making when considering the risks associated with climate change. This precautionary principle has been reiterated in the Victorian Marine and Coastal Policy (2020). **There are also good reasons to support increasing the sea level allowance defined in earlier VCS iterations, given increasing knowledge and understanding of factors such as compounding hazards, wave setup/runup changes and tidal amplification effects on storm surges.**
5. The Portland tide gauge is the most relevant tide gauge for monitoring sea levels for coastal communities in the Port Fairy region and is used by the BoM to provide informal and in future more formal flood watch alerts to GHCMA and Moyne Shire Council for Port Fairy and Warrnambool. Data from this tide gauge is also useful used in modelling supporting successive IPCC reports. Any local sea level projections should be added to the local mean sea level which

‘grounds’ the future sea level to a vertical datum of the locality and makes the changes relevant to the local communities. As sea level rises, the average measured mean sea level at Portland can be tracked and compared to the projections. In this way, the local change in sea level can be readily monitored and linked to predicted time frames associated with signals, triggers, and thresholds in any adaptation pathway. **The data available from the Portland tide gauge clearly shows an upward trend in the rate of sea level rise, with the current rate of rise in the order of 3.4mm per year (average).**

6. Within the exhibited Port Fairy Floodplain Development Plan is included the recommended minimum flood level (Nominal Flood Protection Level, NFPL) based on the 1% AEP flood level for the 1.2m mean sea level rise scenario with no added freeboard. A 1.2m increase in sea level can be expected at Portland (and Port Fairy) by around 2098. At this point in time, buildings with floors finished at the 1%AEP flood level that accounts for 1.2 m sea level rise will no longer have any margin of safety above 1% AEP floods. **To maintain a reasonable safety margin, it would be appropriate to begin adding a freeboard margin to this flood level estimate well prior to actual attainment of this sea level rise impact threshold (suggested time frame of 2058).**
7. **The projected operable lifespan of the proposed controls is around 36 years. Applying a similar logic to the previous control based on a 1% AEP storm tide with 0.8m sea level rise allowance plus 600mm freeboard the operable lifespan of the control would be around 30 years**.
8. The proposed approach setting the NFPL by adopting the 1.2m sea level allowance with a 1% AEP storm tide and no freeboard differs from the traditional approach applied in the Glenelg Hopkins Region which has been to apply a minimum freeboard margin to adopted 1% AEP design flood level estimates. The difference is subtle in that a freeboard margin is built into a higher sea level allowance. Materially, this has limited impact on NFPLs across Port Fairy however it does increase the flood extent captured within the control. **This inclusion of additional properties within the overlay provides for consideration of the uncertainty in predicting rates of sea level change and of the compounding risks associated with climate change on both coastal and catchment flooding (IPCC, 2022), follows the precautionary approach to managing the flood risk between the 0.8m and 1.2m SLR thresholds, and is consistent with an adaptation pathways approach to sea level rise flood risk management as conveyed by the Marine and Coastal Strategy**.
9. The CMAs proposed approach of linking future increases to the NFPL to measured changes in sea level aims to establish a clear framework for decision making that fully accounts for the wide range of plausible impact trajectories in concert with local observation of change. The Portland tide gauge provides a local reference for measuring actual sea level rise which can be clearly tracked against projected changes. Tracking annual mean sea level trend data is the main way to evaluate whether actual change is tracking within the projected range or if sea level locally is changing slower or faster than both global rates and the projected local rates. This aligns with Draft Marine and Coastal Strategy (DELWP, 2021) which sets out to "review the planning benchmarks for rises in sea level based on the latest and best available science (IPCC reports)" and to "establish a process for future reviews of planning benchmarks so that they are aligned with the findings of future IPCC reports and assessments.

7. **Declaration**

I have made all the inquiries that I believe are desirable and appropriate and no matters of significance which I regard as relevant have to my knowledge been withheld from the Panel.

Appendix A

Christine Lauchlan Arrowsmith

Christine is a highly experienced water and coastal engineer and has over 22 years' experience in river, estuary and coastal investigations, from the analysis of river, estuary and coastal processes through to both physical and numerical modelling of such systems. She spent 8 years in the UK, working on Sustainable Urban Drainage Systems (SUDS) design, drainage networks, and dam engineering. Since 2008 Christine has been working in Australia on a range of water related projects, focusing on the analysis of; river systems (flood studies, hydraulic-geomorphic analysis, eco-hydraulics and scour), estuaries (environmental flow requirements, water quality, monitoring programs), and coasts (coastal processes, coastal erosion and inundation hazard assessments, coastal adaptation studies, outfalls and water quality, asset management). Over the last 10 years Christine has been involved in over a range of climate change and adaptation related project.

Education

Bachelor of Engineering (Civil) with Honours, University of Auckland, 1996

Doctor of Philosophy, University of Auckland, 1999 (Thesis title: Pier Scour Countermeasures)

Professional Experience

September 2020 - current	Principal Engineer, Streamology
January 2020 - August 2020	Principal Consultant, Wavelength Consulting, Australia
2018 to 2020	Operations Manager, Australian UAV, Australia
2008 to 2018	Senior Principal Engineer, Water Technology Pty Ltd, Australia
2006 to 2008	Senior Engineer, MWH UK Ltd (Dams Group). UK
2001 to 2005	Engineer/Senior Engineer, HR Wallingford, UK
2000 to 2001	Post-doctoral Fellow, Delft University of Technology, Delft, The Netherlands
1999 to 2000	Lecturer, Civil Engineering Department, University of Auckland, New Zealand
1998 to 1999	Engineer, Pattle Delamore Partners, Auckland, New Zealand

Specialist Technical Areas of Expertise

- Hazard assessments including climate change impacts and adaptation
- River, estuarine & coastal processes assessments including sediment transport and water quality
- Monitoring and asset (environmental and built) management
- One, two and three-dimensional numerical modelling for the study of river, & estuarine flows, coastal systems, overland and pipe network flooding, environmental flows, water quality and sediment transport
- Provision of expert witness reports

- Flood mapping, flood mitigation and stormwater treatment studies, including community & stakeholder consultation
- Flood Intelligence Officer for VIC SES

The following selection of recent projects highlights Christine's experience and expertise in climate change and adaptation area.

CLIMATE CHANGE HAZARD AND ADAPTATION STUDIES

Victorian Guideline for Modelling the Interaction of Catchment and Coastal Flooding (VIC)
This guidance was developed to provide advice on the analysis requirements for assessing flood risks affecting coastally connected waterways and their floodplains. The work was peer reviewed and published by DELWP.

Developing an Adaptation Pathways Approach for Floodplain Management in Southwest Victoria (VIC)
Christine worked with the Glenelg Hopkins Catchment Management Authority to develop a logical adaptation pathways approach for managing flood hazards for coastal communities in the region.

Western Treatment Plant, Port Phillip Bay Coastal Hazard State 1 Scoping Study (VIC) -
Christine is currently assisting Melbourne Water in completed the Stage 1 scoping study for a coastal hazard and adaptation study for the Western Treatment Plant.

Tide Gauge Trigger Levels for Sea Level Rise Adaptation Pathways (VIC) - Christine was commissioned by the GHCMA to develop a practical approach for setting coastal flood based floor levels for planning purposes incorporating consideration of sea level rise.

Victorian Guideline for Modelling the Interaction of Catchment and Ocean Flooding (VIC) - This project was to adapt an earlier NSW based guideline document for flood practitioners to account for coastal flooding aspects when assessing flood risks incorporating the latest understand and approaches.

Inverloch Coastal Hazard Study (VIC) - Christine was the Project Director for this project and provided technical oversight across all elements of the study.

Port Phillip Bay Coastal Hazard Study (VIC) - Christine was part of the CSIRO led team who have recently completed the Port Phillip Bay coastal hazard assessment. She high level technical input to the erosion hazard component which involved assessed erosion hazards around the entire shoreline of Port Phillip Bay under current conditions and for a range of future climate scenarios.

Western Port Local Coastal Hazard Study (VIC) - Christine was the Project Manager and Technical Lead for the study coordinating a team of experts in geomorphology, coastal vegetation, coastal flooding and erosion processes. The project outcomes were detailed coastal hazard mapping for erosion and flooding under current and future conditions.

Gippsland Lakes and Ninety Mile Beach Coastal Hazard Study (VIC) - Christine was the technical lead for the estuary erosion hazard assessment component of the study and provided technical review across other aspects of the project.

Kingston Coastal Hazard Adaptation Study (SA) - Christine was the technical lead for the project to develop a coastal hazard adaptation strategy for Kingston council area in SA. This involved coastal hazard mapping, the assessment of risk and then the development of a series of adaptation pathways for Council, include actions around works or planning measures required under future climate conditions.

Denham Townsite Coastal Hazard Risk Management and Adaptation Planning Study (WA) - Christine was the Technical Director for this project which assessed the coastal hazard and develop an adaptation plan for the Denham Townsite under current and future climate conditions.

Bundaberg Coastal Hazard Adaptation Strategy – Phases 1 and 8 (QLD) - Christine was the technical director for the Bundaberg Coastal Hazard Adaptation Strategy project over Stages 1 to 5 of the 8-stage project. The project followed the QCoast2100 approach to hazards and adaptation planning.

Burrabogie Island Coastal Adaptation Project (VIC) - Christine was the technical lead for this project to develop an adaptation strategy for Burrabogie Island, Paynesville in the Gippsland Lakes. The island is susceptible to increased flooding as a result of climate change and Council wished to develop an adaptations strategy for the area.

Other relevant studies include:

- Lower Eyre Peninsula Flood Mapping Review (SA) - a review of state coastal hazard mapping and advise to Council on further works to be completed as part of a longer-term adaptation strategy.
- Kangaroo Island Coastal Hazard Mapping Study (SA) -
- Port Phillip Bay Storm Tide Inundation Study (VIC)
- Barwon South West Local Coastal Hazard Assessment Scoping Paper (VIC)
- HMAS Cerberus Local Coastal Hazard Assessment (VIC)
- Moreton Bay Regional Council Technical Review of Storm Tide Modelling (Phase 3)
- Moreton Bay Coastal Hazard Adaptation Strategy – Phase 2 (QLD)
- Western Treatment Plant Climate Change Hazard Assessment (VIC)
- Inverloch Shared Path Coastal Hazard Assessment (VIC)
- Gippsland Lakes/90 Mile Beach Local Coastal Hazard Assessment Project (VIC)
- Western Port Local Coastal Hazard Assessment Project (VIC)

Christine has extensive experience in developing, calibrating, and using flood models for strategic and statutory planning, infrastructure investigations and design. She has worked in this sector for a range of government and private projects, including the following flood investigations where she was the Project Manager and Technical Lead.

- Snowy River Regional Flood Mapping Study (VIC)
- Fitzroy River and Darlot Creek Flood Mapping Study (VIC)
- Avon River Regional Flood Mapping Study (VIC)
- Seaspray Flood Study (VIC)
- Looma, Wangkatjunka and Warburton Flood Studies (WA)
- Gawler River Flood Modelling (SA)
- Jigalong Flood Study (WA)
- Smith Creek Flood Study (SA)
- Burrumbeet Flood Investigation (VIC).
- Skipton Flood Investigation (VIC).
- Pedler Creek, McLaren Vale Flood Study (SA).
- Buckland Park, Gawler River Flood Study (SA).
- Thomson River Flood Study (VIC).
- Mt Barker Floodplain Mapping Study (SA).
- Light River Floodplain Mapping Study (SA).
- Macalister Flood Study (VIC).
- Numurkah Flood Study (VIC

Relevant Publications

Lauchlan Arrowsmith, C.S. Jeffery, G. and Robertson, P. (2022). Describing and adaptation pathway for coastal floodplain management in southwest Victoria, 2022 Floodplain Management Australia National Conference, Toowoomba

Lauchlan Arrowsmith, C. S. Graham, T. Morden, B. and Jane, M. (2017). Monitoring Estuary Conditions in the Glenelg River Estuary for Environmental Flows, Coasts & Ports 2017 Conference, Cairns, 21-23 June 2017

Lauchlan Arrowsmith, C.S and Stoessell, D. (2016). Understanding the effects of flow regime on the Snowy River estuary, 11th International Symposium on Ecohydraulics 2016

Stork, D. Keogh, E. and Lauchlan Arrowsmith, C.S. (2016). Measuring Estuary Dynamics and Responses to Environmental Flows, 11th International Symposium on Ecohydraulics 2016

Lauchlan Arrowsmith, C.S and McCowan, A. (2015). Estuary Dynamics and Responses to Environmental Flows, 36th IAHR World Congress, The Hague, the Netherlands, July 2015

Lauchlan Arrowsmith, C.S. Brizga, S. and Keogh, E. (2014), Salinity, Water Level, and Flow Considerations for Assessing Environmental Water Requirements of the Lower Latrobe River, 7th Australian Stream Management Conference, Townsville, July 2014

Lauchlan Arrowsmith, C.S and Race, G. (2014). Spatial Assessment of Estuary Shoreline Erosion Susceptibility, Hydrology and Water Resources Symposium, Perth

Womersley, T. Lauchlan Arrowsmith, C.S. Mawer, J. (2013) Implications of Sea Level Rise on Coastal Hazards and Adaptation Options in Western Port, Climate Adaptation Engineering for Cities and Coasts Symposium, Melbourne

Lauchlan Arrowsmith, C.S. Russell, K.L. Mills, R.B. Brizga, S (2012). Assessing Hydraulic and Geomorphological Threats on the Snowy River Floodplain, 6th Australian Stream Management Conference, Canberra

Lauchlan Arrowsmith, C.S. and Hinwood, J. (2011). Sediment Dynamics of the Snowy River Entrance, 34th IAHR Congress, Brisbane, Australia