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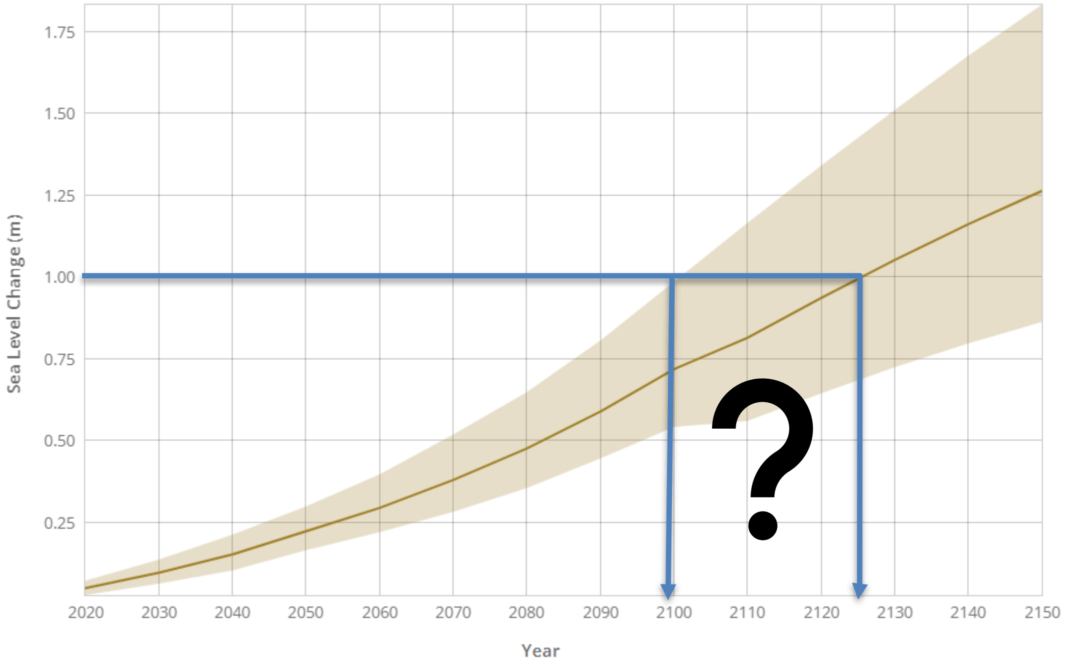
Tide Gauge Trigger Levels for Sea Level Rise Adaptation Pathways



Report for Glenelg Hopkins Catchment Management Authority

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Glossary & Acronyms

1%AEP Flood – A flood of this magnitude has a 1% chance of occurring in any given year. However, a flood of this magnitude (or greater) may occur more frequently than once in any year. The adopted 1% AEP design flood extent and level is the minimum standard for land use and development planning decisions in Victoria (the planned for flood level). There is always a possibility that floods larger in height and extent than the adopted 1% AEP design flood may occur in the future. The 1% AEP flood is not the probable maximum flood (PMF).

ABSLMP refers to the Australian Baseline Sea Level Monitoring Program which has been collecting high quality measured water levels at Portland, Lorne, and Stony Point in Victoria since 1991.

AEP (Average Exceedance Probability) - the probability or risk of a flood of a given size occurring or being exceeded in any given year. A 90% AEP flood has a high probability of occurring or being exceeded in any given year; it would occur quite often and would be relatively small. A 1% AEP flood has a low probability of occurrence or being exceeded in any given year; it would be rare, but it would be a relatively large event. A 100-year Average Recurrence Interval (ARI) event is equivalent to a 1% AEP event. A 1% AEP event has a 1% chance of occurring in any year.

AHD is the national height datum that generally relates to height (elevation) of something above mean sea level. Elevation is expressed in metres AHD.

CMA (Catchment Management Authority) - Victorian Catchment Management Authorities are established under the Catchment and Land Protection Act 1994 (the CaLP Act).

DELWP refer to the Victorian Department of Environment Land Water and Planning

Design flood level - a probabilistic or statistical estimate of flood level (magnitude) derived via computer modelling techniques and based on some form of probability analysis of flood and/or rainfall data. An ARI or AEP is attributed to the design flood level estimate.

Floodplain Management Authority - In Victoria, the floodplain management authority function is assigned under the Water Act 1989. The Victorian Planning Provisions Practice note ‘Applying for a Planning Permit under the Flood Provisions’ identifies CMA's and Melbourne Water as the Victorian floodplain management authorities.

Freeboard - is a height allowance above a design flood level (estimated via modelling) used for land use and development planning purposes. In the context of statutory planning for development of flood-prone land, freeboard is applied to ensure building floors are finished at a level higher than the "adopted design flood level" applied in planning decisions by the Floodplain

Management Authority (e.g., Glenelg Hopkins CMA) and Local Government. Freeboard accounts for uncertainties in estimation of the "adopted design flood level". It provides a safety margin protecting buildings and their contents and occupants against flood impacts when floods reach levels higher than the "adopted design flood level". Uncertainties in the "adopted design flood level" include factors such as the effect of waves caused by wind or vehicles moving through a flooded area, or the impact of rising mean sea level.

IPCC refers to the Intergovernmental Panel on Climate Change, which is the United Nations body for assessing the science related to climate change.

MHWS (Mean High Water Springs) is the long term mean of the heights of two successive high waters during a 24hr period when tidal range is greatest (approx. once a fortnight).

Nominal Flood Protection Level (NFPL) is the minimum level (elevation) requirement for building floors and services (e.g., sewer openings & electrical fittings) and is measured in metres AHD. The NFPL affects the height of floors and building services above the ground surface.

contents

1. Introduction

1.1. Background

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 cause of global mean sea level rise since 1970 is anthropogenic climate change (IPCC 5th and 6th Assessment Reports). Based on satellite altimetry observations since 1993, the rates of sea level rise to the north and southeast of Australia have been significantly higher than the global average, whereas rates of sea level rise along the other coasts of the continent have been closer to the global average (Church et. al. 2018)

In June 2018, the Victorian Coastal Council released Victoria's Coast and Marine Environments under Projected Climate Change: Impacts, Research Gaps and Priorities report. The report states that since 1880, sea level along the coast of Victoria has risen 22.5 cm, while projecting rises in sea level of 8–20 cm by 2030 and 20–59 cm by 2070 and increase in sea-surface temperatures by 1.1–2.5°C by 2070.

These findings are confirmed in the 2019 Victorian Climate Projections[1] report which notes that by the 2050s, sea level at Portland in southwest Victoria is expected to rise by a median value of 24 cm (4 mm/year) compared to the 1990s under a high emissions scenario (Clarke et al, 2019).

Increasing mean sea level has significant implications for management of coastal hazard risks into the future. These risks include an increase in areas affected daily by tidal inundation and/or extreme ocean events such as storm tides. Rising sea level also magnifies the challenges posed by coastal erosion and shoreline recession. Catchment Management Authorities (CMAs) are Victoria's regional Floodplain Management Authorities and are charged with providing advice on flood risk. In providing this advice Catchment Management Authorities have an implied duty of care to understand and track the potential impacts of climate change on flood risk.

Whilst currently not clear, Catchment Management Authorities may also in future be involved in the provision of advice pertaining to the management of risks posed by coastal erosion.

Like all coastal CMAs in Victoria, Glenelg Hopkins CMA uses coastal flood risk mapping that shows likely impacts of higher mean sea levels on coastal development into the future. This information has been used to set planning permit conditions for more than a decade in the form of Nominal Flood Protection Levels (NFPL). In general, the NFPL is the minimum recommended height for building floors to avoid the risk of over-floor flooding during the adopted 1% AEP design flood scenario.

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[1] Accessed via https://www.climatechange.vic.gov.au/adapting-to-climate-change-impacts/victorian-climate-projections-2019

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.

Victoria's planning policy has long recognised the need to actively manage flood related sea level rise risk. The first iteration of the Victorian Coastal Strategy (2008) established overarching policy for managing the sea level rise risk and clause 13.01-2S of the Victoria Planning Provisions translates this into Victoria's landuse and development planning system. Most importantly, Clause 13.01-2S says the landuse and development planning system will "plan for sea level rise of not less than 0.8 metres by 2100".

However, this is high level direction and clarity is lacking in terms of what practical and adaptable options might look like for translating 13.01-2S into effective on-ground outcomes. It is especially the case when describing a process that:

a) Provides local meaning to high-level policy settings & broad sea level rise projections,
b) Establishes and maintains local knowledge of actual change in sea level locally,
c) Establishes a clear framework for decision making that fully accounts for the full range of plausible impact trajectories in concert with local observation of change,
d) Has built in flexibility to account for altered projections and facilitate orderly change in the direction of management responses, and
e) Builds in clear consideration of the likely lead time needed to set pre planned adaptation options in motion, including access to funding, so that serious impacts can be avoided.

This report synthesizes a range of existing information to address this shortcoming in the current approach. It establishes the local context for the IPCC's sea level rise projections and provides 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 NFPL) may be justified.

While analysing the available data, the project has also highlighted the need to meet other adaptation challenges, beyond the CMAs Floodplain Management Authority Function, such as adaptation of essential service infrastructure to increasingly higher tide levels

1.2. **Scope of Study**

The objective of this project is to provide the Glenelg Hopkins CMA (GHCMA) with information to support design and implementation of a clear and practical pathway for decisions around the adoption and potential future increase in the NFPL applied to coastal development proposals. This information may also be of value in establishing decision points for a range of actions, including for investment in future flood investigations to derive new flood risk mapping that accounts for sea level rise exceeding the current maximum amount accounted for by existing flood risk mapping. This is currently 1.2 m, so the information & methodology derived from this study may, inform future decision to invest in flood risk mapping that accounts for even higher amounts of sea level rise.

It also has 'spin off' benefits in that the analysis has highlighted other sea level rise flood issues which can impact Local Government and could assist them in infrastructure planning, such as road or drainage upgrades to accommodate increasingly frequent flooding which can cause significant disruption to communities.

The study is focussed on the GHCMA region, but the approach is applicable to any location along the Victorian coast.

1.3. Report Structure

The report is structured as follows:

- Section 1 provides the background and scope,
- Section 2 briefly summarises the analysis approach,
- Section 3 details the analysis and main outputs,
- Section 4 outlines options for an adaptation pathway approach, and
- Section 5 provides key learnings including recommendations for adopting a baseline mean sea level, selection adaptation pathways and setting decisions points.

2. **Approach**

2.1. **Overview**

The flow chart below (Figure 1) provides a simple overview of the study approach.

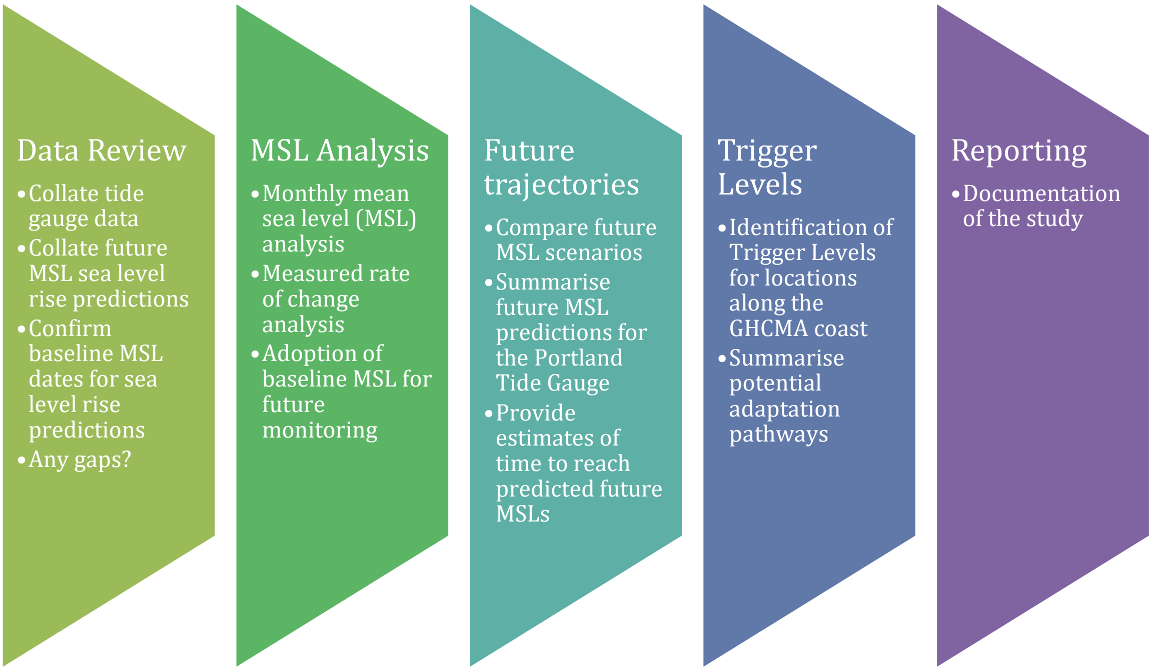

Figure 1 Project Methodology

2.2. **Data & Information Sources**

2.2.1. **Sea Level Data**

The Bureau of Meteorology (BoM) under the Australian Baseline Sea Level Monitoring Program (ABSLMP) has been collecting high quality measured water levels at Portland, Lorne, and Stony Point in Victoria since 1991, Figure 2. The project aims to capture long period sea level changes with an emphasis on enhanced greenhouse effects on sea level, such as those predicted by the Intergovernmental Panel on Climate Change (IPCC). Tide gauge data for Portland extends back to 1982 however the data collected prior to 1991 is of lower reliability than the 1991 to present day data set. There are other tide gauge stations around Victoria, as shown in red in Figure 2. These are operated and maintained by various Port Authorities and are not part of the ABSLMP network.

A summary of the available data for the ABSLMP tide gauges is provided in Table 1. The ABSLMP datasets can be downloaded from the BoM website (http://www.bom.gov.au/oceanography/projects/abslmp/abslmp.shtml). All ABSLMP observed sea level data is in metres above the Tide Gauge Zero (TGZ). To adjust to an Australian Height Datum (AHD) height, the AHD value in Table 1 must be subtracted from the observed sea level data. The Australian Height Datum was established based on approximate mean sea level based on tidal measurements around Australia in 1966-68. Further information regarding AHD can be reviewed here: https://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/ahdgm/ahd. Data is available at hourly intervals as well as monthly statistics. The hourly data is based on six-minute sea level observations.

Monthly sea level data is also available for the other tide gauge stations from the BoM website http://www.bom.gov.au/oceanography/projects/ntc/monthly/. This data is based on hourly sea level observations. For access to the hourly data, you need to contact the Tide Gauge Owner.

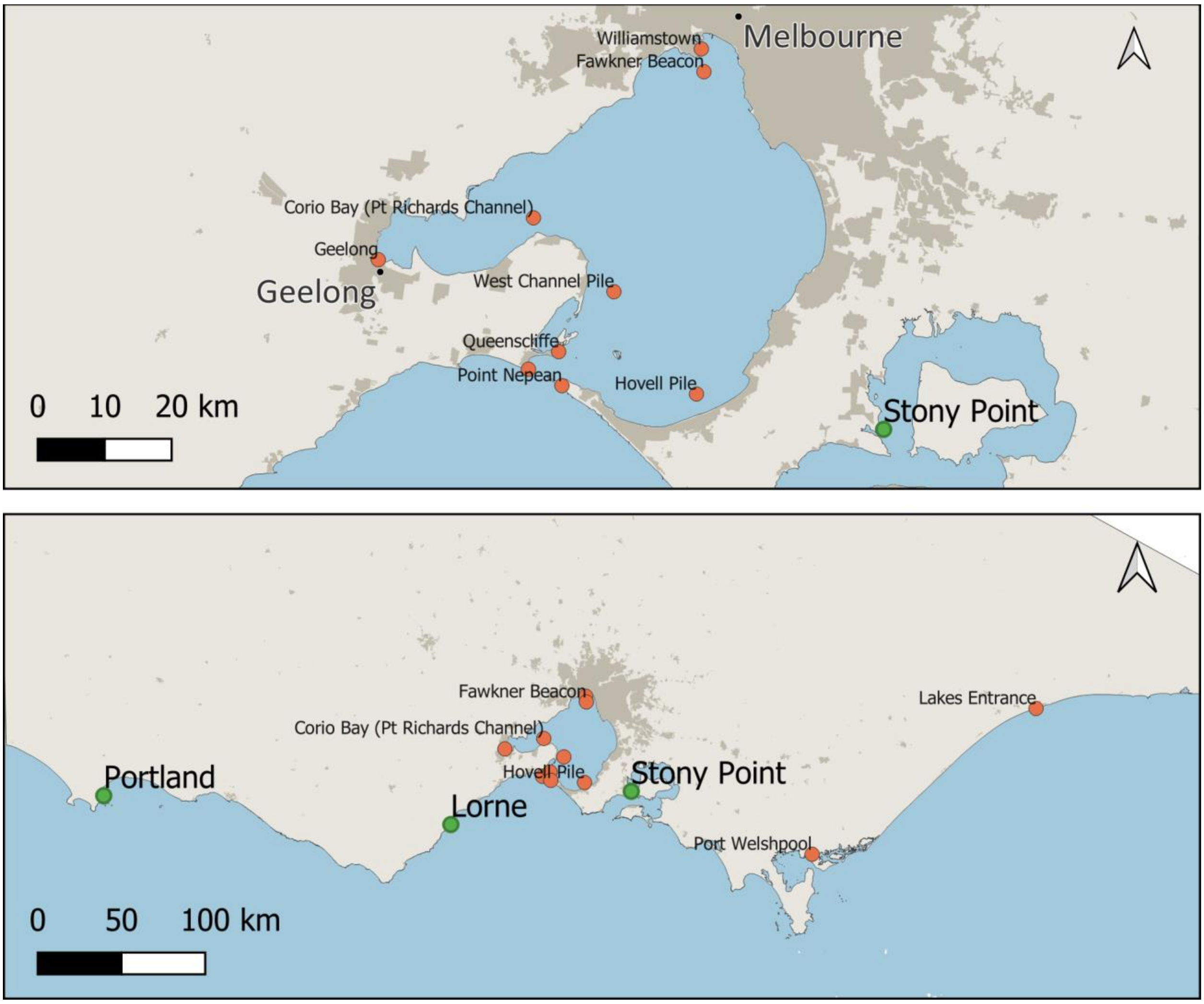

Figure 2 Tide Gauge Locations on the Victorian coast – only the green sites are ABSLMP gauge stations

Table 1 Summary of available ABSLMP sea level data for Victoria

Station	Station Reference	AHD offset	Available Data
Portland	61410	0.507	Tide gauge metadata report Monthly data reports Monthly mean sea level (1991 to present), hourly sea level data (1991 to present) Monthly mean sea level (1982 to present) *
Lorne	60790	1.423	Tide gauge metadata report Monthly data reports Monthly mean sea level (1993 to present), hourly sea level data (1993 to present)
Stony Point	60710	1.690	Tide gauge metadata report Monthly data reports Monthly mean sea level (1993 to present), hourly sea level data (1993 to present)

*the full monthly sea level record from 1982 is also available at the BoM under Tide Gauge Metadata and Observed Monthly Sea Levels and Statistics site: (http://www.bom.gov.au/oceanography/projects/ntc/monthly/). No information is provided on the difference in accuracy for the data from 1982 - 1990 compared to the 1991-present dataset.

An alternative resource for tide gauge data is the Permanent Service for Mean Sea Level (PSMSL) https://www.psmsl.org/data/obtaining/ which collates tide gauge data from around the world and includes data for Victorian tide gauge sites. The data sets from this service are recorded in a relative reference level and so must be adjusted to either the TGZ or AHD levels.

2.2.2. Sea Level Trends and Future Projections

The National Tide Gauge Facility of the BoM undertakes monthly analysis of the tide gauge records to determine sea level rise trends which are provided as monthly data reports (see

Table 1). Each report summarises the quality of the data captured at all the sea level monitoring stations and tabulates the short-term sea-level trend for the entire record (to the given date) and changes from the previous month's analysis.

The most relevant peer reviewed articles on sea level trends around Australia are:

- White, N.J.; Haigh, I.D.; Church, J.A.; Koen, T.; Watson, C.S.; Pritchard, T.R.; Watson, P.J.; Burgette, R.J.; McInnes, K.L.; You, Z.J., and Zhang, X., 2014. Australian sea levels—Trends, regional variability and influencing factors. Earth-Science Reviews, 136, 155– 174.
- Watson, P.J., 2020. Updated mean sea-level analysis: Australia. *Journal of Coastal Research*, 36(5), 915–931. Coconut Creek (Florida)

Sea level projections are estimates of future sea levels based on modelling of a range of future scenarios. Sea level projections are produced periodically by the Intergovernmental Panel on Climate Change (IPCC), which is the United Nations body for assessing the science related to climate change (https://www.ipcc.ch/). The IPCC has recently (August 2021) finalised the first part of the Sixth Assessment Report. This is called "Climate Change 2021: The Physical Science Basis, the Working Group I contribution to the Sixth Assessment Report".

The previous IPCC 5th Assessment Report[2] sea level projections can be accessed at the Climate Change Australia website via the Marine Explorer for Portland and Stony Point https://www.climatechangeinaustralia.gov.au/en/projections-tools/coastal-marine-projections/marine-explorer/

The IPCC 6th Assessment Report Sea Level Projection Tool https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool provides rate of rise projections for Portland, Lorne, and Stony Point. There nearest additional projections are available for Eden (NSW), Burnie (Tasmania) and Victor Harbour (South Australia).

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[2] Refer to Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 2013: Sea Level Change. 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

3. **Tide Gauge Analysis**

To develop an understanding of what impact future increases in sea level will have on the Victorian coast we need to answer the following questions:

- What is the current mean sea level?
- How is this mean sea level changing in Victoria (i.e., what is the Victorian sea level trend)?
- How does the measured rates of change at tide gauges compare to projections for future sea level trends?
- At what time in the future will locations along the southwest Victorian coast reach specific sea level rise thresholds?

3.1. **Mean Sea Level - what is the baseline?**

Monthly mean sea levels are reported for tide gauges around Australia, and include the Victorian tide gauges at Portland, Lorne, and Stony Point. The monthly mean sea level data for Portland are shown in Figure 3. To use the data to measure how much sea level rise has occurred we need to define a baseline or starting point. The agreed baseline also needs to be comparable to the baseline used in sea level rise projections.

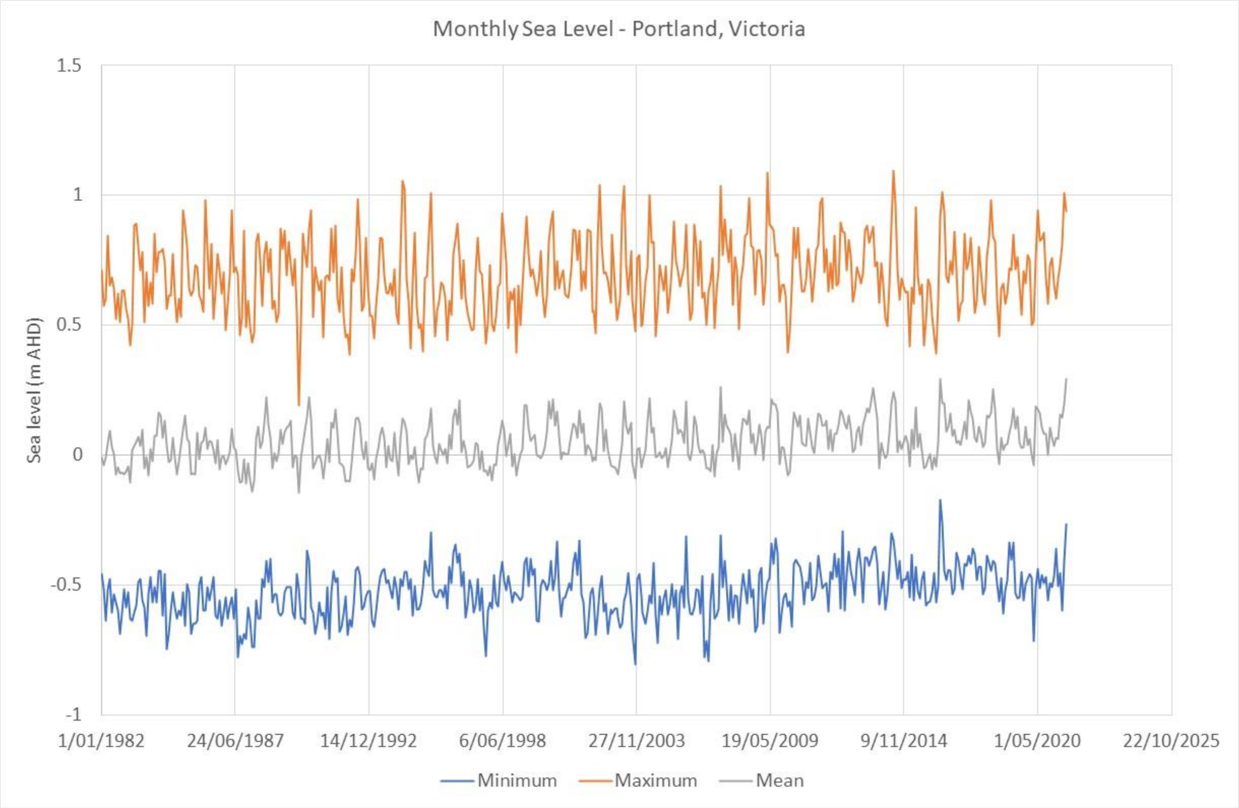

Figure 3 Monthly mean sea level data at Portland, Victoria

The sea-level rise projections, discussed in Section 3.2, are based on a specific baseline period, which differs depending on when the projections were published. The baseline for each IPCC report is chosen for the purposes of assessing the changes evident in successive iterations of climate models used in the IPCCs assessment process and is selected to be as close to present day as feasible, allowing for the fact that an averaging period is required to account for natural variability. Generally, an averaging period of 20 years is selected for practicality even though 30 years is generally considered to be better for averaging out natural climate variability signals such as El Nino Southern Oscillation. The longer the averaging period the further back in time the mid-range of the averaging period is (Dr Kathy McInnes, CSIRO, *pers comm*.).

Table 2 lists the average local mean sea level (MSL) over the various IPCC assessment baseline periods for sites along the Victoria coast; both relative to the relevant local vertical datum and the Australian Height Datum (AHD). The sea level projections in other reports (including some of the Glenelg Hopkins region coastal flood investigations) are sometimes referenced relative to the mean sea level in 1990. The average mean sea level for Portland during 1990 is included. Measurements are not available for the other sites until 1993 so a 1990 average cannot be calculated. The average mean sea level in 2020 for all three sites is included for comparison.

Table 2 Mean Sea Level (MSL) at locations along the Victorian coast averaged over the relevant baseline period (used by the IPCC reports) for adding on sea-level rise projections

Gauge site	Averaging period	MSL (m; local gauge datum)	MSL (m; AHD)
Portland	IPCC 4th Assessment 1980-1999[3]	0.528	0.021
	IPCC 5th Assessment 1986-2005	0.540	0.033
	IPCC 6th Assessment 1995-2014	0.566	0.059
	Jan to Dec 1990	0.541	0.034
	Jan to Dec 2020	0.590	0.083
Lorne	IPCC 4th Assessment 1980-1999[4]	1.472	0.032
	IPCC 5th Assessment 1986-2005[3]	1.485	0.045
	IPCC 6th Assessment 1995-2014	1.505	0.061
	Jan to Dec 2020	1.497	0.074
Stony Point	IPCC 4th Assessment 1980-1999[3]	1.712	0.022
	IPCC 5th Assessment 1986-2005[3]	1.723	0.033
	IPCC 6th Assessment 1995-2014	1.740	0.050
	Jan to Dec 2020	1.755	0.065

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[3] The Portland gauge data commences in January 1982 and therefore the average is over the available data period only

[4] The Lorne and Stony Point gauge data commences in 1993 and therefore the average is over the available data period only

For the purpose of achieving the GHCMAs floodplain management adaptation objective, the recommended baseline value for comparing future measured changes in mean sea level to predictions is the 1995-2014 baseline (IPCC 6th Assessment). The baseline MSL at Portland is 0.059 m AHD.

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.

For example, if a given climate emissions scenario in the 6th Assessment IPCC report predicts a MSL increase of 0.8 m by 2100 at Portland, the baseline MSL is 0.059 m AHD giving a projected MSL at 2100 of 0.859 m AHD at Portland.

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. The published MSL values on the BoM website are relative to the local gauge zero datum and can be converted to AHD as noted in Table 1.

All the various IPCC assessments baseline averaging periods are provided in Table 2 to allow comparison to previous analyses and reporting if required. For example, the most recent State-wide storm surge and storm tide estimates for the south-west Victorian coast are from McInnes et al (2009) which was based on the IPCC 4th Assessment.

3.2. Future Sea Level - what are the current and projected trends?

As a result of sustained warming of the atmosphere through the enhanced greenhouse effect from emissions since the Industrial Revolution, the ocean and land–ice environments have been gradually changing. Global and regional increases in surface temperature, along with wind and ocean circulation, drive most of the processes that affect sea-level rise.

Local sea level rise is the local change in sea level relative to the land at a specific point on the coast, measured by a sea level (tide) gauge. The gauge measures the combined effects of absolute sea level rise for the regional sea and other regional and local processes, for example, oceanographic circulation patterns, hydrology cycles (water use and storage), and local and/or regional vertical land motion (subsidence or uplift). So local sea level rise varies between coastal regions (Bell *et al* 2017).

For assessing impacts and adaptation pathways for specific locations along our coast we are interested in the trend of mean local sea level measurements collected at the closest tide gauge location. Figure 2 shows the mean sea level "signal" as recorded by the Portland tide gauge since 1982 and this gauge is clearly of primary interest in terms of a methodology underpinning coastal NFPL decision making in the Glenelg Hopkins region.

3.2.1. **Current sea level trends**

The analysis of trends in mean sea level from tide gauge records is complicated in that there are a range of natural climate variability signals within the datasets as discussed in Section 3.1. The gauge record at the Portland tide gauge is >30 years, while the Lorne and Stony Point datasets are ~30 years in length and so they do provide a length of record which captures much of the natural climate variability for the region.

Monthly short-term sea-level rise (SLR) trend reports (rate of movement in mm/year) are provided by the BoM for all ABSLMP stations. 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 individual station. The data for Portland was extracted from these BoM reports.

Indicative statistics for the sea level trend data at Portland are provided in Table 3. This data has only been made available by the BoM for the years 2000 to present.

Table 3 Short-term sea-level trends at Portland

Short-term sea-level trend (2000 to 2021)	Rate of movement (mm/year)
Average	3.4
Median	3.1

The average rate of movement was determined by averaging all the monthly rates of movement over the full data period available (2000-2021). The rate of mean sea level movement was generally higher in 2001 and 2002 but has been quite consistent from 2002 to 2021.

3.2.2. **Future sea level trends and the influence of emissions.**

Climate projections are based on sophisticated national and international global climate models. These models use the physical laws that govern the Earth system to simulate the climate. The models run on some of the world's most powerful supercomputers, and successfully represent the important features of today's climate as well as those of the past (VCC, 2018).

To cover a range of future possibilities, scientists use emissions scenarios to develop climate projections. For IPCC Assessments up to and including the 5th Assessment (IPCC 2014) these scenarios were the Representative Concentration Pathways (RCPs). Three of these RCPs are described below:

- The lowest emissions scenario, called RCP 2.6 leads to about 1.5 °C of global warming, and would see carbon dioxide equivalent concentrations reach about 490 ppm
- RCP 4.5 is a stabilization scenario and assumes that climate policies, such as the introduction of a set of global greenhouse gas emissions prices, are invoked to achieve the goal of limiting emissions. To meet the Paris Climate Agreement, the world needs to be on at least an RCP 4.5 pathway.
- RCP 8.5 represents fast population growth, a low rate of technological development and high energy use, sometimes referred to as 'business as usual'.

VCC (2018) provides predictions of sea level rise for RCP 2.6 and 8.5 based on the IPCC 5th Assessment report. Since then, the 6th Assessment report has been released along with updated projections.

In the IPCCs 6th Assessment Report, the scenarios now incorporate 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)[5]:

- 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.
- 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.
- 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.

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. The sea level change projections for Portland under SSP4.5 SSP8.5 and SSP8.5 *low confidence* are presented in Figure 4, Figure 5 and Figure 6 respectively.

The figures present the median value of the predicted sea level rise (solid line) along with confidence limits (17th to 83rd percentiles, shaded colours) based on the combined results of all

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[5] 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/

the different national and international global climate models. If you were to look at the results from a specific global climate model for a given SSP scenario, the modelled results would likely lie within the confidence limit range.

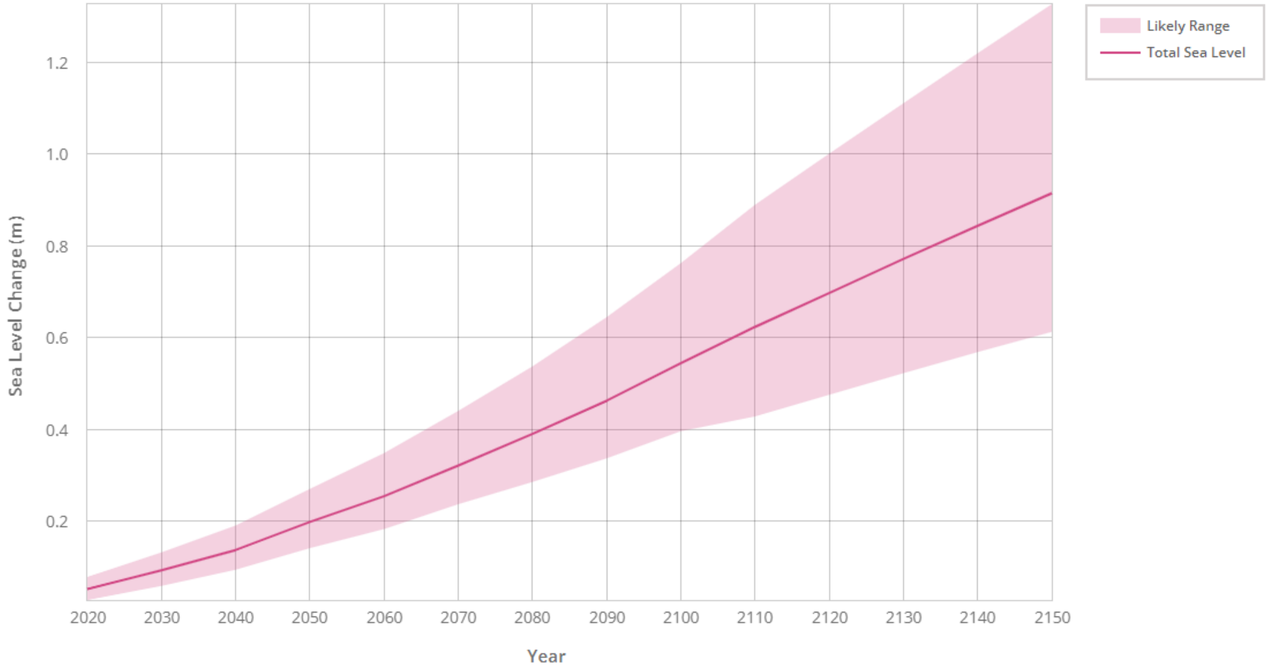

Figure 4 Sea level change at Portland under SSP4.5 relative to a 1995-2014 baseline (NASA Sea Level Projection Tool, accessed 2/10/2021)

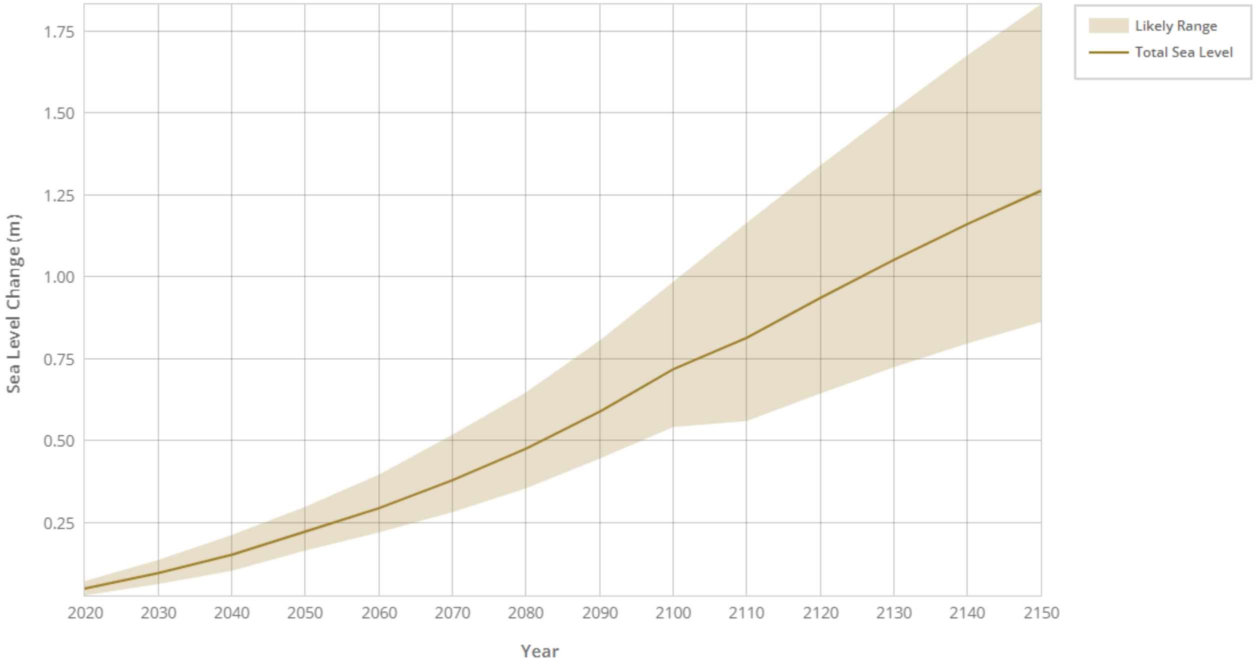

Figure 5 Sea level change at Portland under SSP8.5 relative to a 1995-2014 baseline (NASA Sea Level Projection Tool, accessed 2/10/2021)

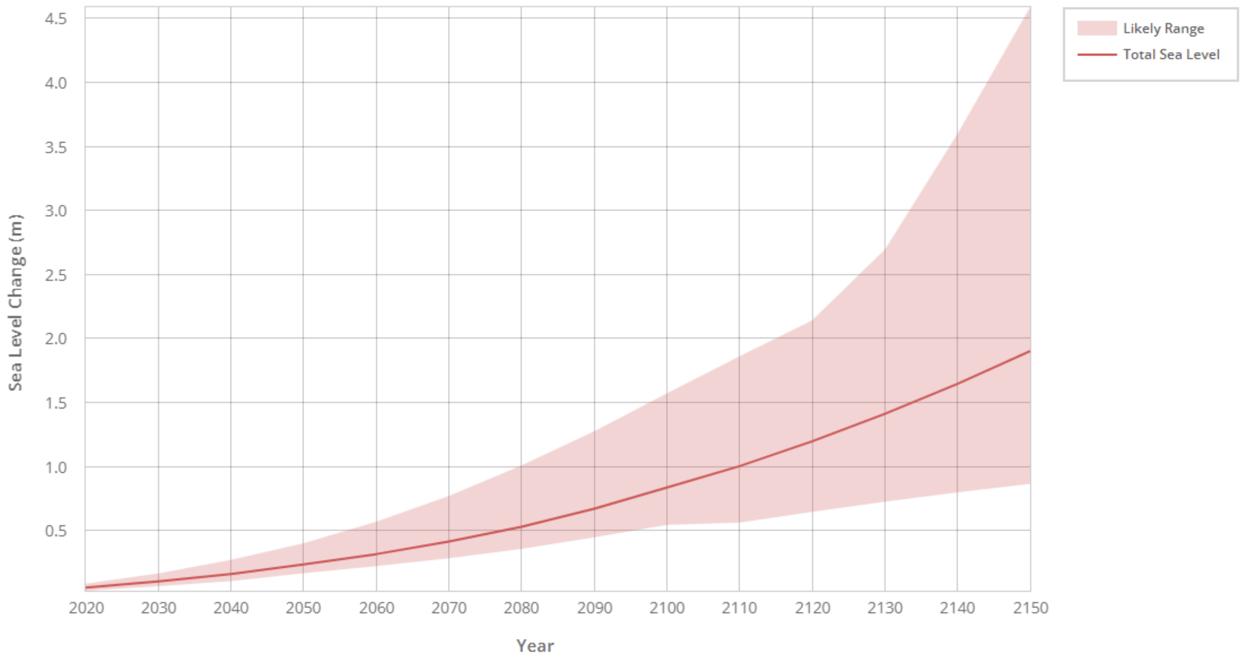

Figure 6 Sea level change at Portland under SSP8.5 *low confidence* relative to a 1995-2014 baseline (NASA Sea Level Projection Tool, accessed 2/10/2021)

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 4. 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 4 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

3.2.3. Sea Levels and Timing

The sea level projection tool associated with the IPCC 6th Assessment report includes an analysis of the likely time frames for which different sea level rise increments could be expected to be reached under the different future scenarios. The results are presented for Portland in Figure 7 to Figure 12 for sea level rise increments of 0.2 m, 0.8 m, 1.0 m, 1.2 m, and 1.4 m respectively. These increments are relative to the 1995-2014 baseline mean sea level. The circles show the median value, while the bar represents the range of the confidence limits (17th to 83rd percentiles), while the extremes (5th to 95th percentiles) are shown by the thin bars for the low confidence scenarios only.

You can see that for the 0.2 m sea level rise increment (Figure 7) all the future scenarios predict a similar time frame to reach this threshold and have narrow confidence limits. This is because even with future reductions in carbon emissions all the models predict that 0.2 m increase in sea level rise is almost certain to occur. For example, the best-case scenario (SSP1.9) is almost the same as the worst-case scenarios (SSP8.5 & SSP2.6 *low confidence*). The wider range of predictions for future sea level increments shown by Figures 6 through 11 reflect the potential benefits of future reductions in carbon emissions in slowing the rate of sea level rise. This also shows the importance of understanding the assumptions underpinning future sea level rise projections adopted for planning purposes and the need for decision making processes to be readily adaptable as confidence around the likely timeframe for attainment of higher (than 0.2) increments of sea level rise increases.

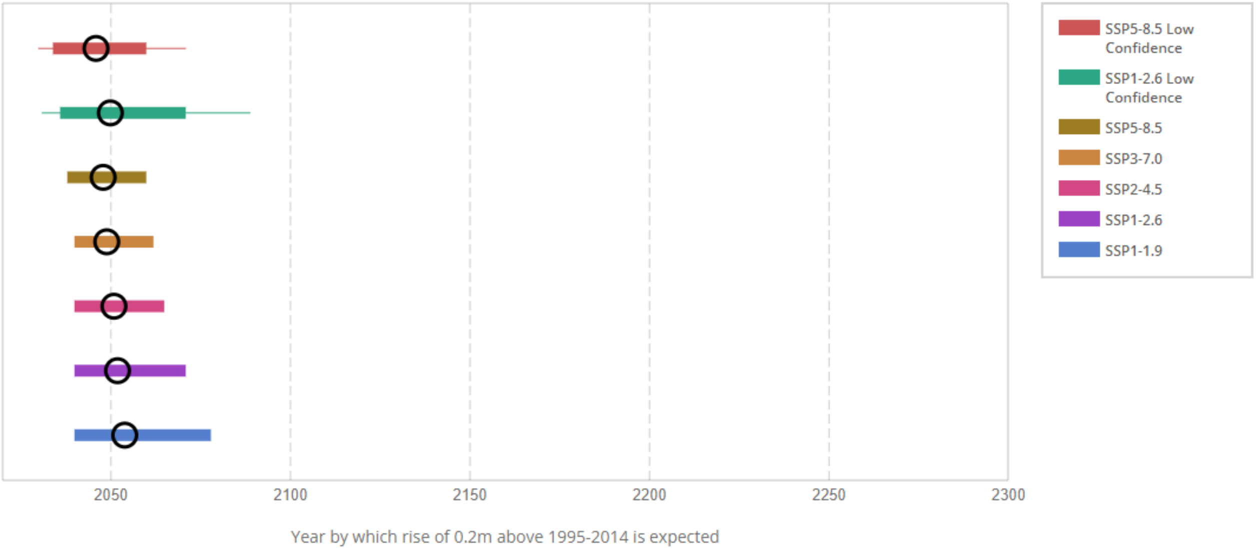

Figure 7 IPCC 6th Assessment Report – timeline for sea level rise of 0.2 m at Portland (NASA Sea Level Projection Tool, accessed 2/10/2021)

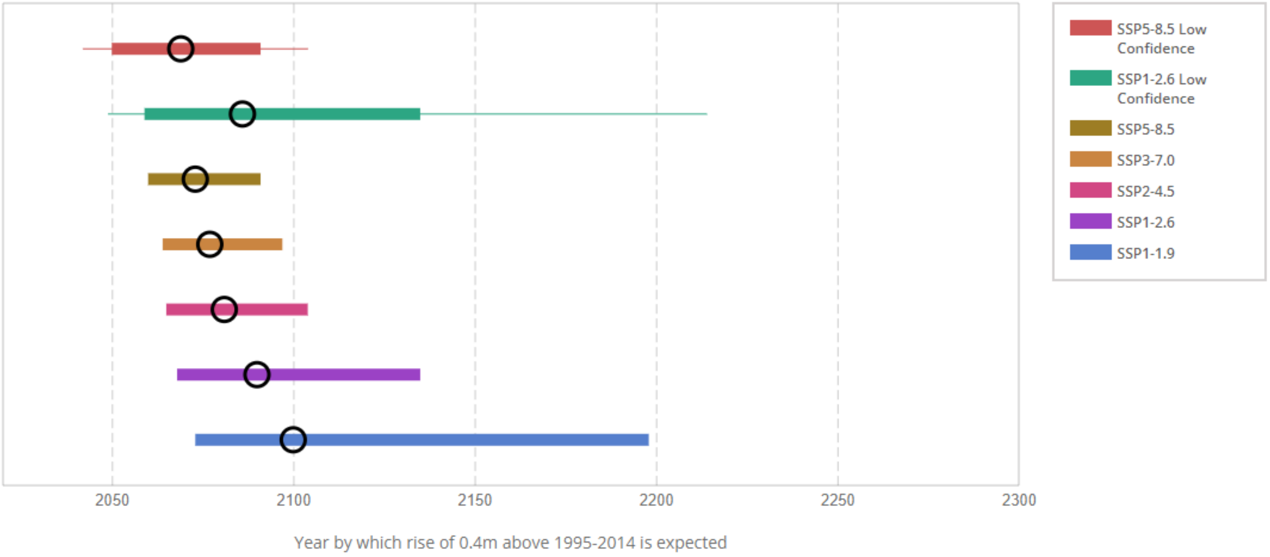

Figure 8 IPCC 6th Assessment Report – timeline for sea level rise of 0.4 m at Portland (NASA Sea Level Projection Tool, accessed 2/10/2021)

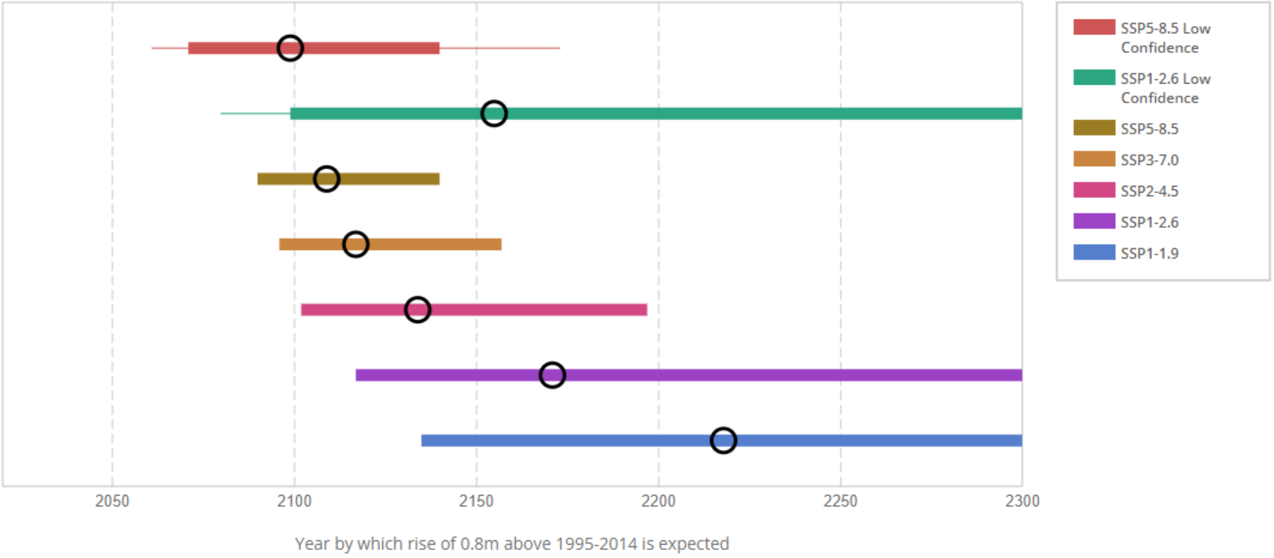

Figure 9 IPCC 6th Assessment Report – timeline for sea level rise of 0.8 m at Portland (NASA Sea Level Projection Tool, accessed 2/10/2021)

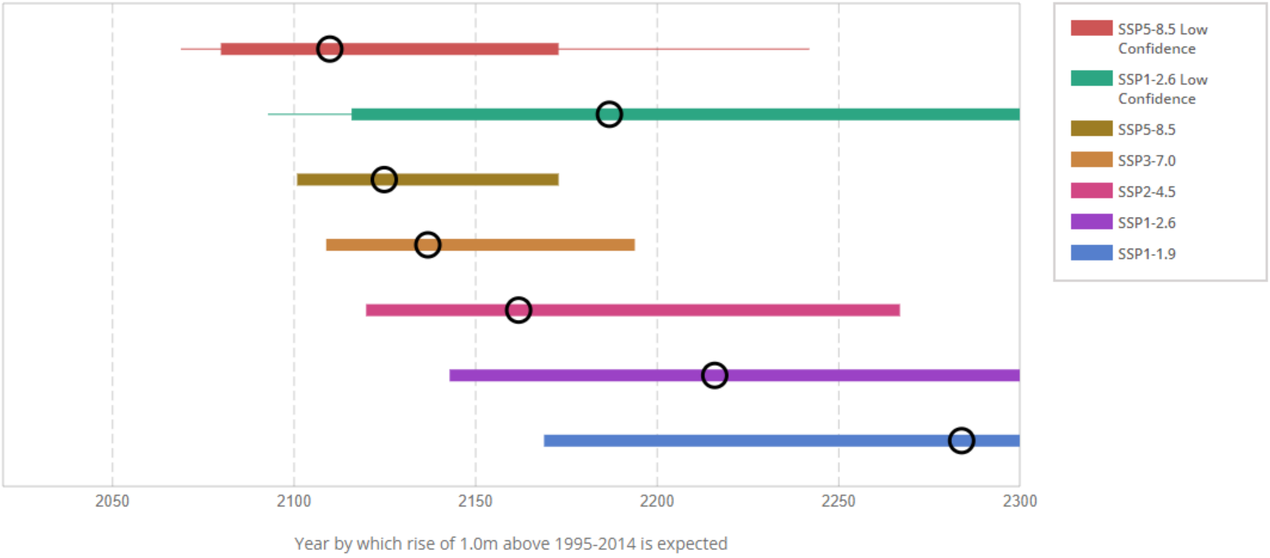

Figure 10 IPCC 6th Assessment Report – timeline for sea level rise of 1.0 m at Portland (NASA Sea Level Projection Tool, accessed 2/10/2021)

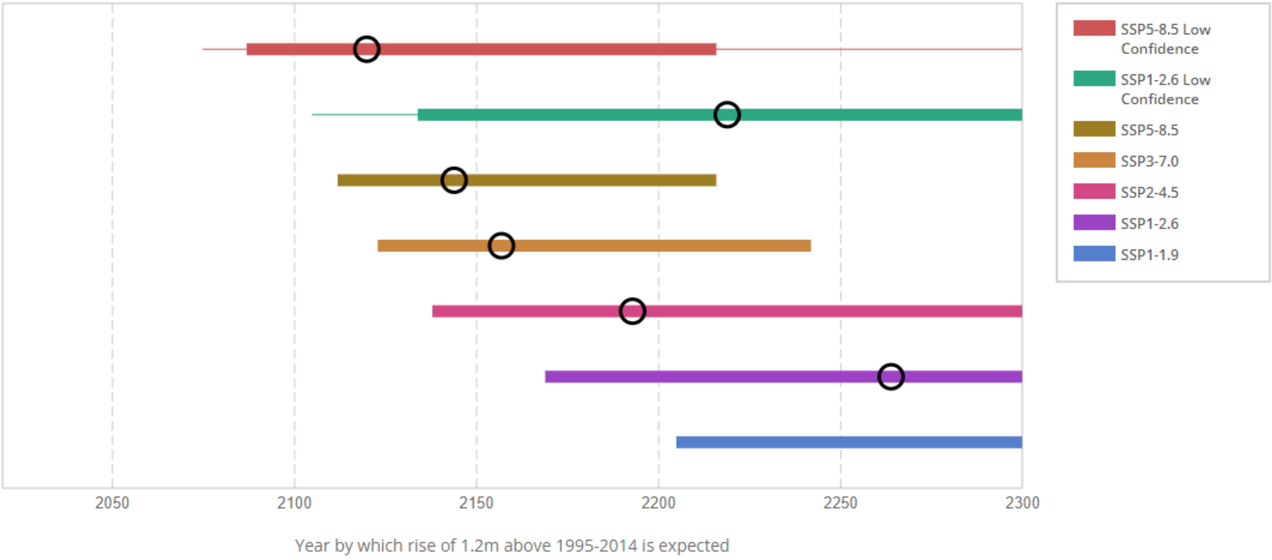

Figure 11 IPCC 6th Assessment Report – timeline for sea level rise of 1.2 m at Portland (NASA Sea Level Projection Tool, accessed 2/10/2021)

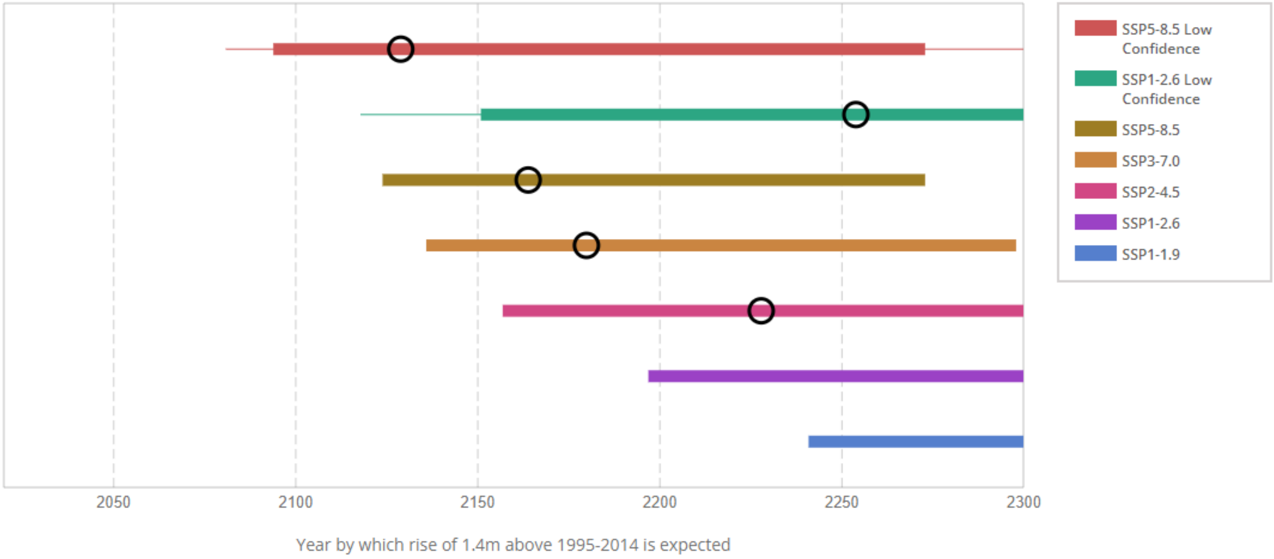

Figure 12 IPCC 6th Assessment Report – timeline for sea level rise of 1.4 m at Portland (NASA Sea Level Projection Tool, accessed 2/10/2021)

The mean sea level value at Portland which equates to the different sea level rise thresholds is shown in Table 5. While the predicted time at which these thresholds are predicted to be reached is summarised in Table 6 and Table 7 for the 50th and 95th percentile predictions. SSP5-8.5 is highlighted as this is the scenario that has previously been adopted for planning purposes in Victoria (Victorian Coastal Strategy, 2014; State Planning Policy Framework Clause 13.01-1).

The United Nations Environment Program provides an annual emissions gaps report, which is a yearly review of the difference between where greenhouse emissions are predicted to be in 2030 and where they should be to avoid the worst impacts of climate change. The 2020 report states that despite a brief dip in carbon dioxide emissions caused by the COVID-19 pandemic, the world is still heading for a temperature rise more than 3°C this century – far beyond the Paris Agreement goals of limiting global warming to well below 2°C and pursuing 1.5°C. This puts the current emissions trajectory in line with the higher emissions scenarios (SSP3-7 and SSP5-8.5).

Given this current trajectory and the potential risks associated with loss of the ice sheets (SSP5-8.5 *low confidence*) the continued adoption of predictions under SSP5-8.5 is recommended when planning for future change.

Table 5 Predicted Mean Sea Level values at Portland for sea level rise thresholds above the 1995-2014 baseline

Sea Level Rise threshold	Predicted Equivalent Mean Sea Level at Portland Tide Gauge (m AHD)	Predicted Equivalent Mean Sea Level at Portland Tide Gauge (TGZ)
0.4	0.459	0.966
0.8	0.859	1.366
1.2	1.259	1.766
1.6	1.659	2.166
2.0	2.059	2.566
2.4	2.459	2.966

Table 6 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	-	-	-
SSP1-2.6 *(low confidence)*	2052	2090	-	-	-	-	-
SSP5-8.5 *(low confidence)*	2048	2062	2095	2121	2139	-	-

Table 7 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	-
SSP1-2.6 *(low confidence)*	2034	2048	2080	2103	2130	-	-
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, as shown in Figure 13 and Figure 14.

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.

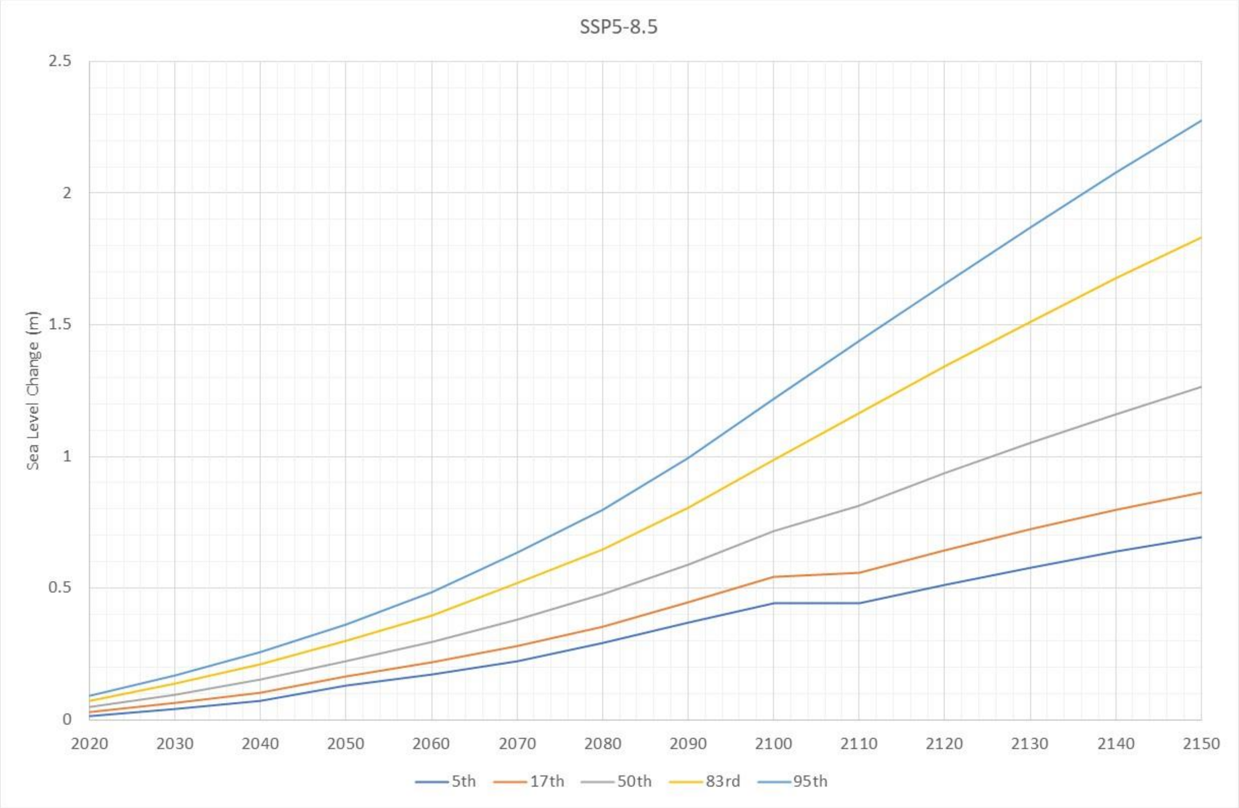

Figure 13 Predicted sea level change at Portland under SSP8.5 (NASA Sea Level Projection Tool, accessed 2/10/2021)

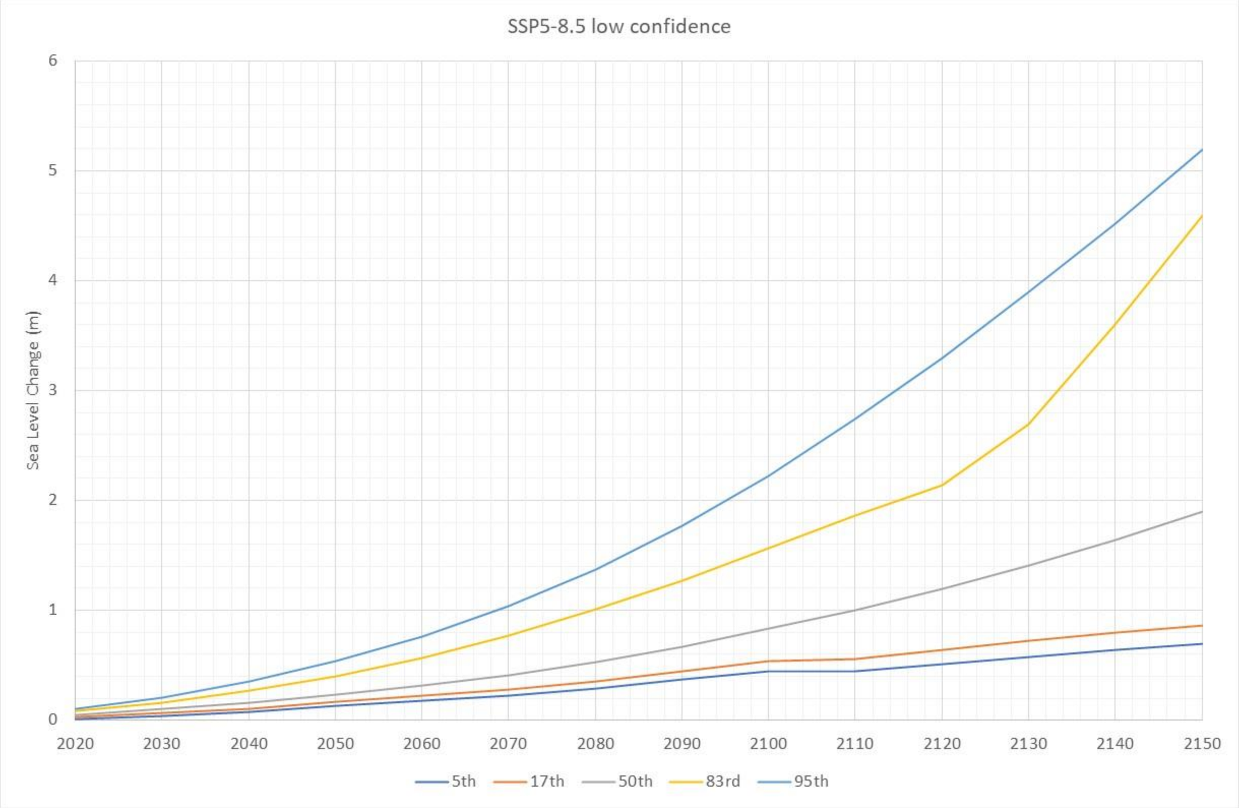

Figure 14 Predicted sea level change at Portland under SSP8.5 (low confidence) (NASA Sea Level Projection Tool, accessed 2/10/2021)

4. **Adaptation Pathways**

4.1. **Overview**

As the information presented previously shows, the time it takes for mean sea level to increase is uncertain and depends on future emissions strategies adopted both in Australia and globally. From a Victorian planning perspective, 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[6]*, 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.*

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. 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

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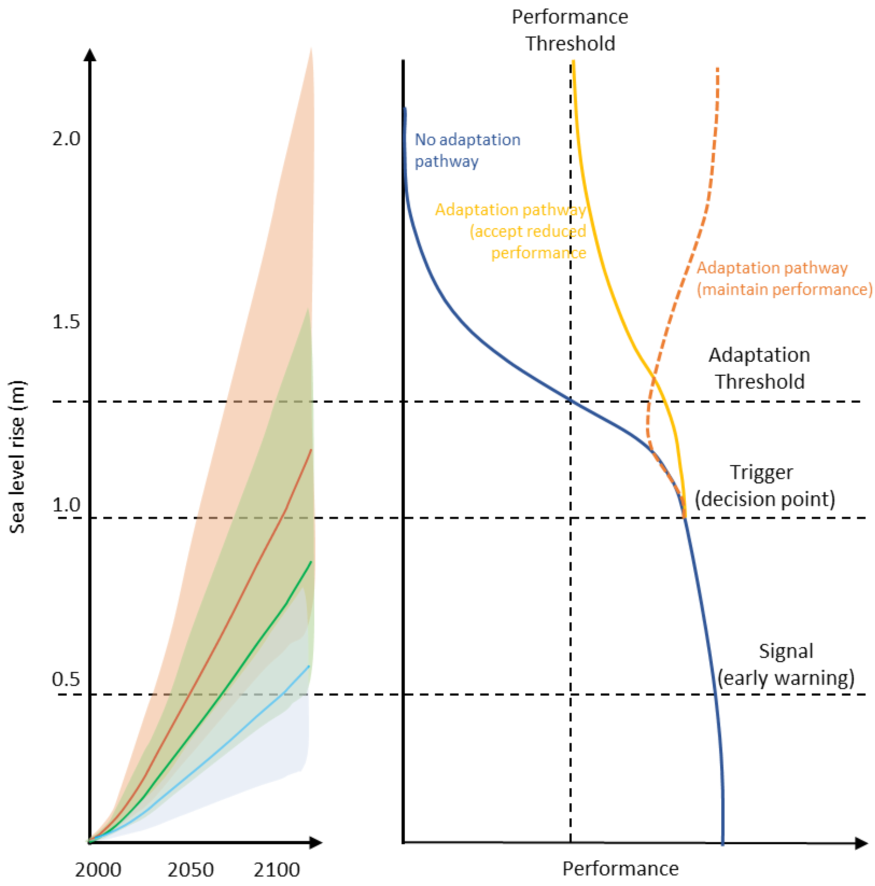
[6] The high emissions scenario refers to SSP5-8.5

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 as a consequence 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 15.



Adaptation Threshold – the point beyond which undue harm and adaptation cost is likely to occur unless adaptation actions are implemented

Trigger – a decision point for selecting an adaptation pathway

Signal – an early warning which alerts decision makers to a pending decision point trigger. The signal provides time to decide which option(s) to take when the decision

Figure 15 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)

4.2. **What Thresholds, Triggers, and Signals can be applied for Adaptation?**

Several types of thresholds, triggers, and signals could be adopted for decision making in the Glenelg Hopkins CMA region. This section describes how these elements might be applied.

4.2.1. **Flood level based**

A flood-level based approach is centred on monitoring increments of sea level rise and setting a decision-making signal a certain period (say 10 years) prior to an adaptation decision point trigger being reached. The amount of lead time should be sufficient to enable considered reassessment of any pre-planned adaptation options (pathways) such as raising the NFPL and revising planning controls or design of new options if necessary. Longer lead times may be needed depending on the options being considered, especially if a preferred pathway option involves implementing physical flood protection works or if it becomes evident that there is a need to design new options.

Example 1 - flood levels and defined lead times

An example of a flood level based approach is shown in Table 8 using local sea level thresholds and projections at the Portland tide gauge. If an adaptation threshold is set at 0.8 m of relative sea level rise, this threshold could be expected to be reached at Portland by 2080 (highlighted in green). A decision-making trigger point is then set ~10 years prior in 2070 when the local mean sea level has reached 1.14 m TGZ (0.63 m AHD). This example is based on the SSP5-8.5 scenario sea level projections using the more conservative 95th percentile (i.e., higher) estimates.

Table 8 Indicative adaptation thresholds and triggers under SSP5-8.5 (IPCC 6th Assessment Scenarios)

Adaptation threshold (rel. sea level)	Threshold likely to be reached by (95th percentile, SSP5 8.5)	Time MSL trigger level is reached	Trigger sea level at Portland (TGZ)	Trigger sea level at Portland (m AHD)
0.4	2053	2043	0.81	0.30
0.8	2080	2070	1.14	0.63
1.2	2098	2088	1.46	0.95
1.6	2117	2107	1.89	1.38
2.0	2136	2126	2.30	1.79

Table 9 shows the same analysis but applying a more extreme sea level rise projection scenario (i.e., SSP5-8.5 *low confidence*). Under this scenario the adaptation threshold of 0.8 m of relative sea level rise could be reached by 2062, setting a decision-making trigger 10 years earlier in 2052 when the local mean sea level reaches 1.11 m TGZ. So, if the rate of sea level rise was to follow this more extreme scenario the thresholds and triggers would be reached earlier.

An option could be to use this more extreme sea level rise scenario as an indication of the "earliest" likely timeframe-based adaptation trigger for increasing the NFPL and initiation of investment in new flood risk mapping for sea level rise increments greater than 1.2m which is the highest sea level rise scenario currently accounted for by existing flood risk mapping for the region.

Table 9 Indicative SLR thresholds and triggers under SSP5-8.5 *low confidence* (IPCC 6th Assessment Scenarios)

Adaptation threshold (rel. sea level)	Threshold likely to be reached (95th percentile, SSP5 8.5 *low confidence*)	Time MSL decision trigger level is reached	Mean Sea Level decision trigger at Portland (TGZ)	Mean Sea Level decision trigger at Portland (m AHD)
0.4	2046	2036	0.77	0.26
0.8	2062	2052	1.11	0.60
1.2	2074	2064	1.39	0.88
1.6	2086	2076	1.74	1.23
2.0	2095	2085	2.01	1.50

Example 2 - NFPL threshold levels and decision trigger points

Alternatively, rather than focussing on a defined lead time, the decision trigger could be set based on a specified reduction in the NFPL. For instance, at Port Fairy it is proposed that the nominal flood protection level (NFPL) is set at the 1% AEP flood level estimate incorporating 1.2 m sea level rise, with zero freeboard added. The best available Information shows that if this level is adopted for landuse and development decision making, it will provide in the order of 0.6 m of freeboard over 1% AEP flood levels up until the time at which mean sea level has actually risen by 0.8 m. In other words, this NFPL should provide approved buildings with an adequate safety margin over 1% AEP flood levels up until about 2080, based on the SSP 8.5 emissions scenario. The best available information discussed above, shows that a 1.2m Increase in sea level can be expected at Portland (and Port Fairy) by around 2098 (highlighted in green in Table 10). 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.

Table 10 Indicative adaptation thresholds and triggers under SSP5-8.5 (IPCC 6th Assessment Scenarios) – Port Fairy example

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

A trigger threshold has been set in this example for when the NFPL is reduced to ~0.6 m, which is a value typically applied as a freeboard margin when including the effects of sea level rise (see Planning Practice Note 11, 2015; DELWP, 2019).

In the Port Fairy example, attainment of the less than 0.6 m freeboard margin threshold will be signalled when the Portland tide gauge shows an average reading of 1.17 TGZ (equivalent to 0.66 m AHD) (highlighted in orange in Table 10). This tide gauge reading could be the trigger for adding freeboard to reset (revise upward) the NFPL. Based on the SSP5-8.5 projection, this level could be reached by around 2068. From 2068, the factor of safety of the NFPL above the 1% AEP floods at Port Fairy will continue to reduce as sea level continues to rise until the adaptation threshold level is reached.

Setting an early warning signal at lower adaptation threshold (say 10 years prior to the NFPL trigger level) may be warranted if there are concerns about the adequacy of existing flood risk protection measures for the community.

4.2.2. **Impact based**

Hague et al (2020) has outlined an approach to defining impact-based thresholds for coastal tide gauges using reports of coastal inundation. In that report, impact-thresholds are set based on the observed frequency of impacts of high sea levels on specific locations along the coast. These high sea levels can be the result of a range of physical causes. Another way to look at impact thresholds is to consider what the impact of permanent increases in tide level (as a consequence of sea level rise) will be on the functionality of essential services infrastructure like stormwater drainage systems and roadways.

This is a useful approach as the change in tidal levels with sea level rise is likely to be a more obvious indicator of arising challenges due to the increase in permanently inundated land during each high tide compared to the impacts of relatively infrequent storm tide events. Only limited research has been completed to date on the change in frequency of storm tide events because of sea level rise. However, it can be expected that sea level values currently considered to be unusually high (e.g., a 1% AEP storm tide) will occur much more regularly in the future as sea level continues to rise.

Table 11 presents an example of an impact based approach using the Portland tide gauge and the mean high-water springs (MHWS)[7] tidal level. This is the high tide level you could expect to see every 2 weeks. As sea level rises, the MHWS level increases. With only 0.21 m of sea level rise, the MHWS at Portland will be at the same level as what is current considered a 50% AEP storm tide event (i.e., a storm tide event that could be expected about every 1.44 years). Assuming the 95th percentile rate of sea level rise under SPP5-8.5 emissions scenario is the actual trajectory followed, by 2064 we could expect up to 0.55 m of sea level rise. This would raise the MHWS level to the same level as what can currently be expected during a 1% AEP storm tide. In the absence of investment in adaptation, there is a real risk of regular and significant inconvenience through flooding of roads or inundation of property simply because of high tides.

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[7] MHWS - long term mean of the heights of two successive high waters during a 24hr period when tidal range is greatest (approx. once a fortnight)

Table 11 Indicative MHWS level at Portland for different SLR increments with the equivalent storm tide and indicative time frames when the level could be reached (IPCC 6th Assessment Baseline and Scenarios). Storm tide levels based on McInnes et al (2009)

Threshold SLR increment (above 1995-2014 baseline MSL)	MHWS[8] (m AHD)	Equivalent Current Storm Tide AEP - Portland	Time MHWS sea level is reached (50th percentile, SSP5 8.5)	Time MHWS sea level is reached (95th percentile, SSP5 8.5)
0.00	0.54	-	-	
0.21	0.75	50%	2049	2035
0.26	0.80	20%	2055	2040
0.33	0.87	10%	2064	2047
0.47	0.97	5%	2080	2058
0.51	1.05	2%	2084	2062
0.55	1.09	1%	2086	2064

Figure 16 provides an example of what this regular impact might look like at Port Fairy using existing bathtub storm tide mapping for the 1% AEP storm tide under current mean sea level conditions (Water Technology, 2010). This map shows the 1% AEP storm tide flood level is close to existing development, including roads.

Figure 16 Flood Map for Port Fairy for the 1% AEP storm tide, current mean sea level (bathtub modelling, from Water Technology, 2010)

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[8] From the Victorian Tide Tables 2021 (available through https://vrca.vic.gov.au/recreational/victorian-tide-tables/).

Whilst the MHWS tidal level at Port Fairy is practically the same as Portland, the MHWS level at Warrnambool is lower at around 0.34 m AHD (VRCA, 2021). The best available information shows the storm tide AEP levels increase slightly from Portland to Port Fairy (see McInnes et al, 2009). Table 12 and Table 13 present the analysis results for Port Fairy and Warrnambool. The 50% and 20% AEP storm tide levels are not presented for Port Fairy and Warrnambool as these are not available from McInnes et al (2009). The storm tide values for these events at Portland were based on analysis of the Portland tide gauge data presented in Water Technology (2008).

Table 12 Indicative MHWS level at Port Fairy for different SLR increments with the equivalent storm tide and indicative time frames when the level could be reached (IPCC 6th Assessment Baseline and Scenarios). Storm tide levels based on McInnes et al (2009)

Threshold SLR increment (above 1995-2014 baseline MSL)	MHWS[9] (m AHD)	Equivalent Current Storm Tide AEP - Port Fairy	Time MHWS sea level is reached (50th percentile, SSP5 8.5)	Time MHWS sea level is reached (95th percentile, SSP5 8.5)
0.00	0.54	-	-	
0.37	0.91	10%	2068	2050
0.47	1.01	5%	2079	2057
0.51	1.09	2%	2084	2062
0.59	1.13	1%	2091	2066

Table 13 Indicative MHWS level at Warrnambool for different SLR increments with the equivalent storm tide and indicative time frames when the level could be reached (IPCC 6th Assessment Baseline and Scenarios). Storm tide levels based on McInnes et al (2009)

Threshold SLR increment (above 1995-2014 baseline MSL)	MHWS[10] (m AHD)	Equivalent Current Storm Tide AEP - Warrnambool	Time MHWS sea level is reached (50th percentile, SSP5 8.5)	Time MHWS sea level is reached (95th percentile, SSP5 8.5)
0.00	0.34	-	-	
0.59	0.93	10%	2072	2061
0.70	1.04	5%	2091	2069
0.77	1.11	2%	2106	2078
0.80	1.14	1%	2108	2080

In terms of defining an adaptation pathway for this kind of impact, a threshold (or multiple thresholds) could be set at a specific equivalent current storm tide AEP level, with the trigger being the likely time this could be realised under the SSP5-8.5 50th percentile, and a signal set at the predicted 95th percentile date.

This sort of impact-based threshold is now being used for informal flood watch alerts for Port Fairy and Warrnambool. GHCMA and Moyne Shire Council have started to receive these alerts from the BoM when the Portland tide gauge level is predicted to reach 1.6 m TGZ (1.09 m AHD), which is equates to between a ~2-5% AEP storm tide (present day sea level). At this high sea level water

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[9] From the Victorian Tide Tables 2021 (available through https://vrca.vic.gov.au/recreational/victorian-tide-tables/)

[10] From the Victorian Tide Tables 2021 (available through https://vrca.vic.gov.au/recreational/victorian-tide-tables/)

goes over Ocean View Drive on the south side of Port Fairy and begins to inundate low lying areas alongside the Port Fairy wharf (see Figure 17). It also inundates land up to the doorstep of some properties in Warrnambool as shown by the Glenelg Hopkins CMA's June 2014 flood extent map (Figure 18). The June 2014 storm tide event reached 1.6 m TGZ and is the highest sea level yet, recorded at Portland (1982-2020). Regular tidal inundation around this height could be expected fortnightly at Port Fairy by 2062 simply as a consequence of the higher tide conditions that could be "normal" for this future time period.

Figure 17 Water over the accessway beside the Port Fairy wharf during the June 2014 flood event (Courtesy of the Warrnambool Standard)

Figure 18 Aerial view of the June 2014 flood extent map for South Warrnambool (mapped flood extent highlighted in pink)

4.2.3. Monitoring thresholds, triggers, and signals

While these thresholds, triggers and related signals can be set up now, they must be periodically reviewed and updated if necessary. The values presented here represent only the first step in an iterative process. A review process could be based on a regular sea level trend report like that produced by the South Australian Department for Environment (e.g., DEW Technical note 2020/25 https://data.environment.sa.gov.au/Content/Publications/RC2020_TechNote_Climate_SeaLevel.pdf). The BoM produces monthly sea level trend reports which can be aggregated into such a report. The actual measured sea level trends at tide gauges along the Victorian should be included if this approach were to be adopted.

The frequency of any reporting could be linked to the predicted time frame associated with the earliest signal, trigger, or threshold. As a starting point, the reporting period could be linked to the IPCC report cycle (in the order of 6 to 7 years), or when significant revision of the climate change model predictions have occurred. An example of such a revision is the inclusion of the SSP5-8.5 low confidence scenario in the IPCC 6th Assessment report. 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 activates 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."

As mentioned in Section 2, the BOM publishes monthly sea level trend and mean sea level data. The data for Portland, Lorne and Stony Point can be tracked on a monthly or annual basis and compared to the selected prediction scenario. Figure 19 provides an example tracking chart for the Portland tide gauge.

Only the 2020 mean sea level change projection 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) is presented in Figure 19. The 2020 mean sea level change compared to baseline (1995-2014) values at Lorne and Stony Point are 0.012 m and 0.015 m respectively. Signals are indicatively only and are flagged by the sea level that could be observed 10 years before the impact threshold is reached.

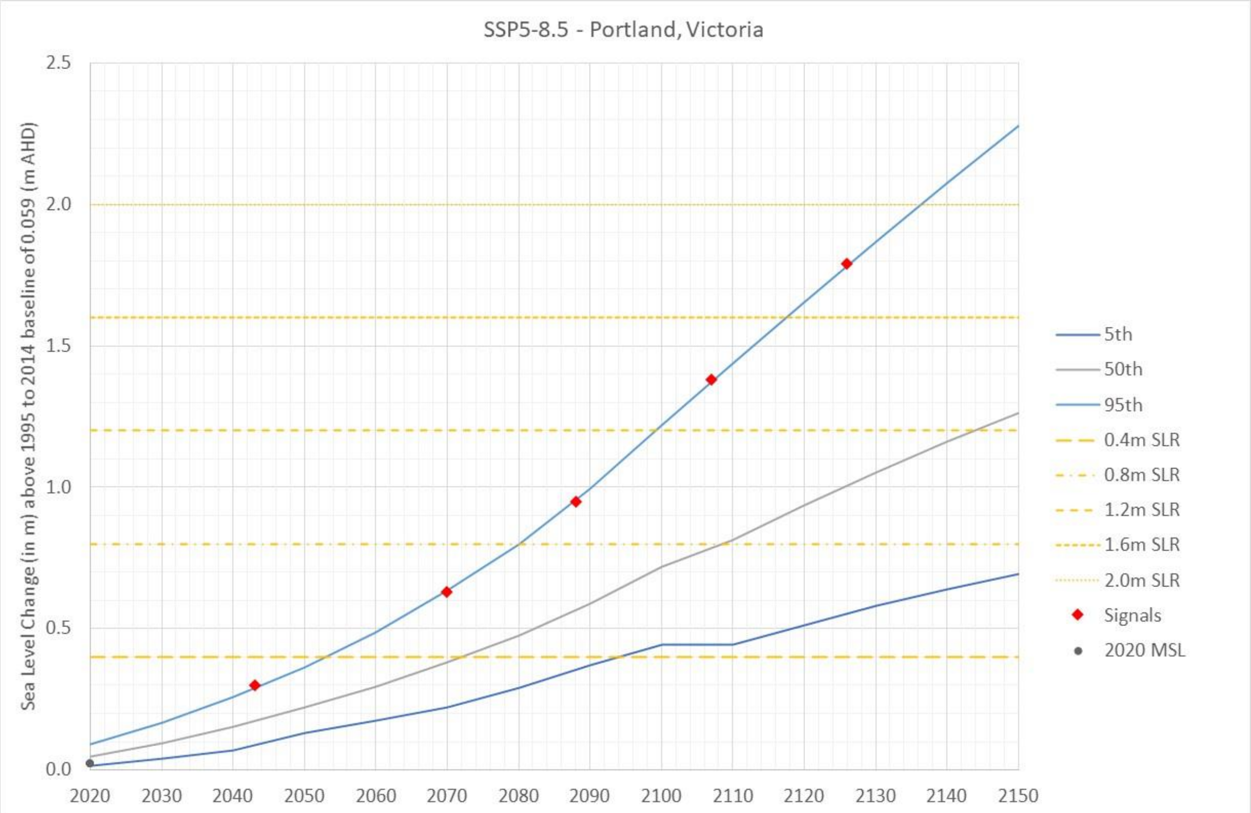

Figure 19 Example showing future mean sea level projections (SPP5-8.5) along with sea level increments (rel.), and possible signals relative to the adopted MSL baseline

4.3. Existing Flood Investigations

The existing coastal flood investigations in the GHCMA region were reviewed to confirm which sea level rise increments were considered and the relative impact of coastal and catchment flooding. A summary is provided in Table 14.

Essentially, the rivers with intermittently opening entrances such as the Surrey and Fitzroy Rivers showed limited flood extent sensitivity to sea level rise. In these locations, it is expected that the entrance berm will likely increase in elevation as a response to sea level rise. Glenelg Hopkins CMA reports that the increase in berm heights has become increasingly noticeable in the last decade and they are now actively collecting berm height data to support their observations. For open estuaries such as the Moyne River (Port Fairy), the Merri River (South Warrnambool), and Fawthrop Lagoon (Portland), the existing flood investigations indicate how higher mean sea level is likely to influence the extent of riverine dominated floods, and to a lesser extent they also show the potential extent of storm tide dominated floods, noting that the storm tide flood risk is yet to be assessed beyond 0.8 m sea level rise in most locations.

The existing flood investigations show that flood levels and/or extents will be substantially affected by sea level rise at Port Fairy, Warrnambool, and Portland, when the 0.8 m sea level rise threshold is met and exceeded.

Table 14 Summary of coastal flood investigations in the GHCMA region and sea level increments assessed

Flood Study	SLR scenarios	Flood impacts of SLR
Port Fairy Water Technology (2008, 2010) WRL (2013) Cardno (2019)	Various depending on the study. Current proposed planning layer based on: 1% AEP storm tide for 1.2m rel. mean sea level rise	Changes to flood impacts as a result of sea level rise are location specific and depend on whether ocean water levels are the dominant flood mechanism at any given location. The critical SLR increment appears to be > 0.8 m whereby the 1% AEP flood risk along the Moyne River changes from being dominated by catchment geberated floods to ocean generated floods.
Surrey River Water Technology (2008)	1%AEP riverine flood combined with 10% AEP storm tide for: 0.49, 0.80, and 1.2m rel. mean sea level rise	The flood modelling results showed negligible change in flood extents for all the sea level rise scenarios as a factor of the river mouth sand berm (periodically open/closed) nature of the estuary.
Fitzroy River & Darlot Creek Water Technology (2017)	10% & 1% AEP storm tide for: 0.4m rel. sea level rise	As per the Surry River study, the flood modelling showed no impact on catchment flood levels with sea level rise, noting that only 0.4 m sea level rise was investigated.
South Warrnambool Water Technology (2007, 2011, 2013)	10% AEP storm tide for: 0.5 m rel. sea level rise (2007) 0.2 and 0.8m rel. sea level rise (2013)	The modelling showed limited impact of the storm tide on flooding for the 0.2 m sea level rise scenario, but significant increases in extents and depths did occur under the 0.8m sea level rise scenario. The impact was determined to be greater for the 10% catchment flood event than for the 1% AEP catchment flood. The applied ocean boundary was a static peak water level value and is therefore conservative.
Portland Cardno (2011)	1% AEP storm tide for: 0.8 m rel. sea level rise	The report noted that comparing the current conditions (1% AEP catchment flood and 1% AEP storm tide) with the same events but including 0.8 m sea level rise resulted in the depths in Fawthrop Lagoon being increased by approximately 1 m. This was predominantly the result of the higher mean sea levels. All of the floodplain had some increase in depth under the sea level rise scenario.

5. Summary & Recommendations

5.1. Key Learnings

The data analysis shows that if the current trajectory for greenhouse emissions is not lowered:

- The level of flood risk posed by 0.8 m and 1.2 m of relative sea level rise could be realised by 2080 and 2098 respectively and it is not implausible that these impacts could be realized as early as 2062 and 2074 if catastrophic loss of ice from Greenland and/or Antarctica occurs.
- Significant inundation of low-lying areas is likely to occur as a consequence of high tides by around 2057 and again, these impacts may be realised as early as 2046 if catastrophic loss of ice from Greenland and/or antarctica occurs.

The Portland tide gauge represents a significant asset to the region both in terms of monitoring sea level rise and in terms of design and implementation of an effective sea level rise adaptation pathway for the region, noting that:

- Zero on the Portland tide gauge equates to 0.507 m AHD.
- The baseline value for comparing future measured change in sea level should be 0.059 m AHD which equates to 0.566 m on the Portland tide gauge.

Adaptation pathways based around flood level thresholds and / or impact thresholds, with these thresholds clearly related back to mean sea levels at the Portland tide gauge, provide an opportunity to:

- Track changes over time,
- Set triggers for decisions, and
- Develop signals to allow time for:
    - assessing the impacts of changes; and
    - whether previously identified adaptation options are still valid; and
    - making the right decisions early enough to enable implementation of effective adaptation measures.

These aspects are expanded upon in the following sections.

5.2. Selection of Sea Level Projection Pathway

To cover a range of future possibilities, climate scientists use a range of plausible emissions scenarios to develop climate projections. The IPCC 6th Assessment Report calls these future conditions scenarios "Shared Socioeconomic Pathways" (SSP). These were referred to as Representative Concentration Pathways (RCPs) in the 5th Assessment Report.

SSP5-8.5 is a conservative scenario that assumes no additional climate policy/action and continued socioeconomic development using fossil fuels. This is essentially the "business as usual" pathway and has previously been adopted for planning purpose in Victoria (Victorian Coastal Strategy, 2014; State Planning Policy Framework Clause 13.01-1). The current worldwide emissions trend is tracking in line with this scenario (UNEP, 2020). Given this current trajectory and the potential risks associated with acceleration of sea level rise due to the loss of the ice sheets (SSP5-8.5 *low confidence*), continued use of sea level rise projections under SSP5-8.5 is recommended for adaptation planning.

For this report, the SSP5-8.5 50th and 95th percentile projections have been used in the analysis. The 95th percentile represents the extreme value of the projections.

5.3. Adopted MSL Baseline

Each iteration of the IPCC assessment report tends to adopt a different mean sea level baseline which is then used as the reference level for the report's sea level rise projections. The latest report (IPCC 6th Assessment Report) has adopted a mean sea level baseline of the average mean sea level over the period 1995-2014. This is done to make the projections more closely related to the “present day” sea level instead of relating the projection to a level from further in the past.

It is recommended that the 1995-2014 baseline value be selected for comparing future measured changes in mean sea level. The baseline MSL relative to 1995-2014 as measured by the Portland tide gauge is 0.059 m AHD. Any local sea level projections should be added to this baseline figure. This ‘grounds’ the future sea level to a vertical datum relevant to the coastline between Portland and Warrnambool.

For example, if a given climate emissions scenario in the 6th Assessment IPCC report predicts a MSL increase of 0.8 m by 2080 at Portland, the baseline MSL is 0.059 m AHD giving a projected MSL at 2100 of 0.859 m AHD at Portland. This equates to a reading of 1.366 on the Portland Tide Gauge.

5.4. Proposed Adaptation Pathway Logic

Given the uncertainty associated with future sea level change, particularly around the rates of change, it is recommended that Councils and CMAs consider setting both flood-level and impact-based thresholds as part of their adaptation planning moving forward. The following sections present a decision logic for setting a future adaptation pathway.

5.4.1. Flood level based

The existence of high reliability tide gauge data for the regions coastline and almost complete coverage of ''at risk" coastal development areas with flood risk mapping places the region in a good position to take another step forward in the evolution of the sea level rise risk response. 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.

Building active awareness and use of the high reliability sea level data collected by the Portland tide gauge would be central to such an approach. Aside from the technical validity of direct use of the Portland tide gauge in the regions management response, direct reference to the Portland tide gauge data may have spin off value in building community acceptance and confidence in the sea level management response. In other words, the visible use and reference to hard local evidence, as provided by the Portland tide gauge may be more conducive to meaningful local action than reference to broad policy statements and seemingly intangible statements of the need to act coming out of the IPCC reports.

The first step in establishing a pathway approach is selection of an appropriate NFPL. A valid approach could be to adopt a design 1% AEP flood level estimate from one of the modelled future scenario increments with no freeboard margin. 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 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 NFPL set using a projected (future) 1% AEP flood level estimate with no added freeboard.

A conceptual example of how a flood level estimate for a future 1% AEP scenario could work in practice is provided under the adaptation pathway logic graphic show at Figure 20, and a worked example for Port Fairy is shown in Figure 21 (see Section 4.2.1, example 2).

In the adaptation pathway logic, the future flood level selected to be the NFPL becomes the *adaptation threshold*. In the Port Fairy example, this threshold is suggested to be an increase in mean sea level of 1.2 m, as measured by the Portland Tide gauge. The corresponding tide gauge reading is 1.77 m which corresponds to 1.26 m AHD. i.e., an average reading of 1.77 m on the Portland tide gauge will mark attainment of the 1.2 m sea level rise threshold. At this point in time (potentially 2098) buildings with floors finished at the 1.2 m sea level rise flood level estimate (the NFPL) will no longer have any margin of safety above 1% AEP floods.

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 indicative lead time of 10 years is provided as a guide, however any adopted lead time for adaptation planning should be set in consultation with the relevant flood management agencies and Local Government. More time may be necessary where physical works such as relocation of services are to be considered as part of an adaptation pathway or where additional time may be required to obtain funding for further flood studies as well as allow for completion of the studies themselves and the subsequent planning instrument updates.

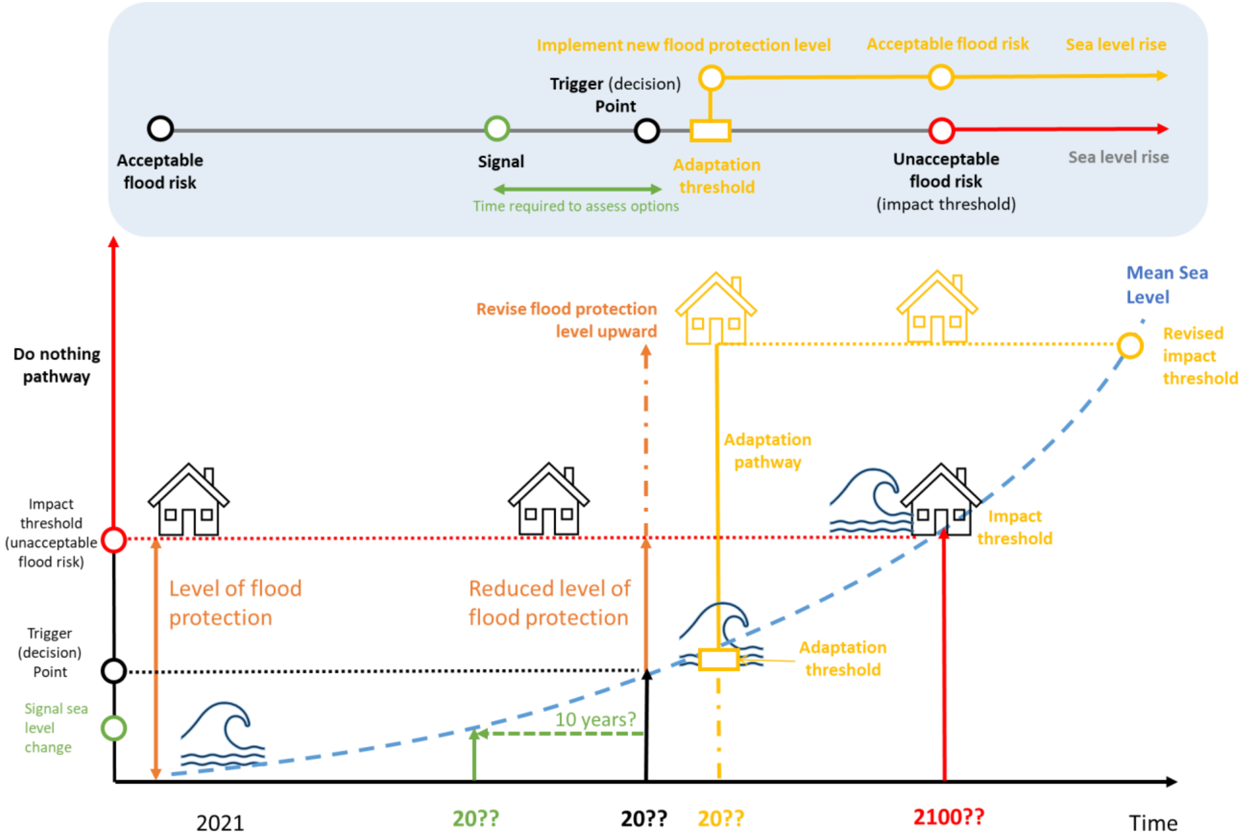

Figure 20 Conceptual model for applying a flood level based adaptation pathway for a coastal community

In the Port Fairy example (Figure 21), the nominal flood protection level (NFPL) is set at the modelled 1.2 m sea level rise flood level scenario, with zero freeboard. Development approved with this floor level should have adequate freeboard (in the order of 0.6 m - essentially the trigger level) up to around 2068 (under the SSP5-8.5 scenario, 95th percentile). This is then adopted as the potential "likely" timeframe (45 years) over which this NFPL could safely operate.

The NFPL resetting process is therefore *triggered* when the Portland tide gauge shows an average reading of 1.17 m (equivalent to 0.66 m AHD) Based on the SSP5-8.5 95th percentile projection, this level could be reached by around 2068

An early warning *signal* could then be nominated for a time at least 10 years prior to the time at which the trigger level is predicted to be exceeded. 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.

In the Port Fairy example, the **signal level at the Portland tide gauge is 1.04 m (equivalent to 0.47 m AHD) and the timeframe to reach this level based on the SSP5-8.5 is estimated to be 2058.**

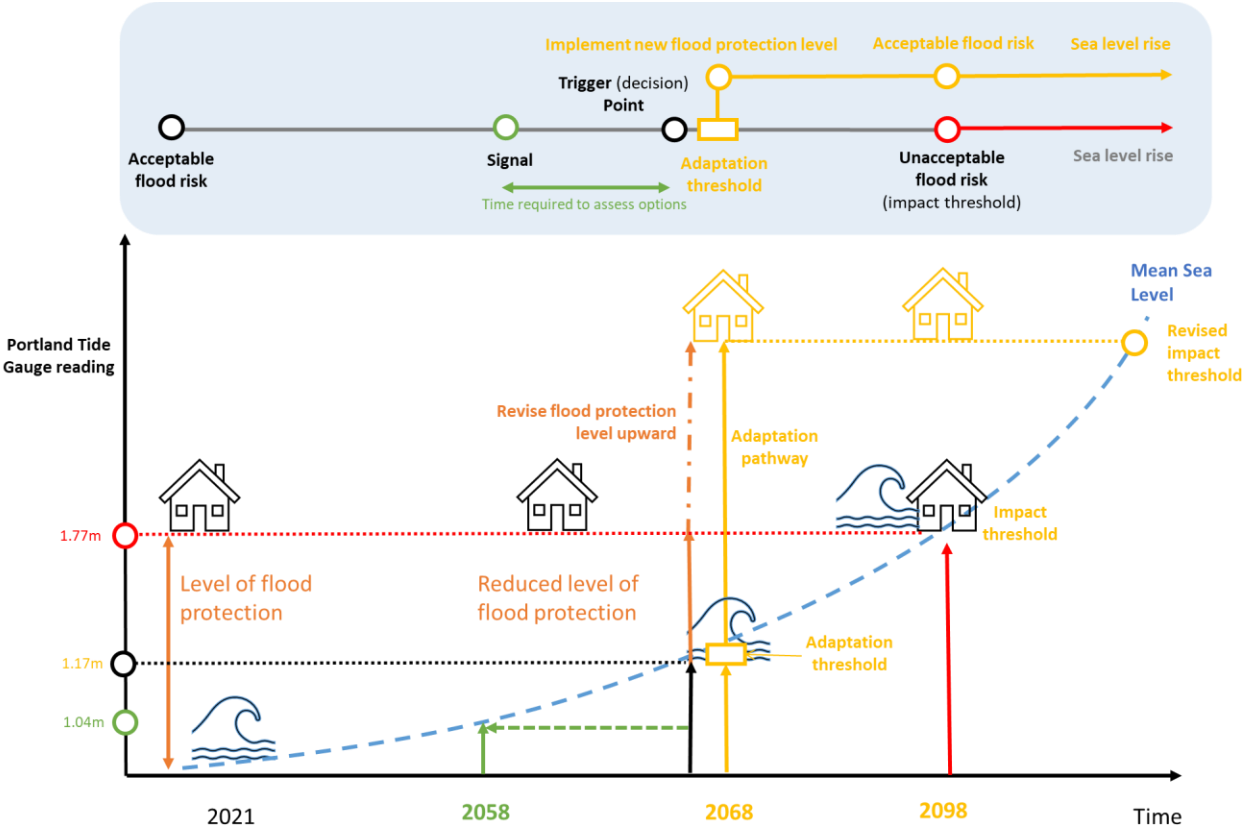

Figure 21 Port Fairy example of applying a flood-level based adaptation pathway

> As shown in this example for Port Fairy, this means that the best estimate of the time over which the 1.2m sea level rise flood level based NFPL might be appropriate is about 36 years. However there is considerable uncertainty in this estimated time frame which is why active monitoring and periodic reassessment (as described further in Section 5.5) should be built into the work program of CMAs and LGAs.

5.4.2. **Impact based**

Although not typically considered in coastal flood investigations in Victoria to date, permanent tidal inundation is likely cause increasingly frequent and significant flood impacts for coastal communities. The analysis in this report has highlighted how the mean high-water springs (MHWS) tidal level (which occurs every 2 weeks) will exceed what is currently the 1% AEP storm tide level when mean sea level rise reaches 1.64 m on the Portland Tide Gauge (around 1.13 m AHD) for the GHCMA region.

This is important for Councils to consider in their future planning as there is the real risk of significant inconvenience through regular flooding of roads or inundation of property.

An example of an impact-based adaptation pathway approach to addressing increasing permanent tidal inundation risks is shown in Figure 22 for Port Fairy. Indicative signal, trigger and threshold sea levels are provided; however, these decision points would need to be defined based on an analysis of what impacts this frequent flooding would cause to the community. The types of adaptation responses could include actions such as raising or re-routing roads, installing backflow prevention gates on drains, or planning for relocation of certain infrastructure.

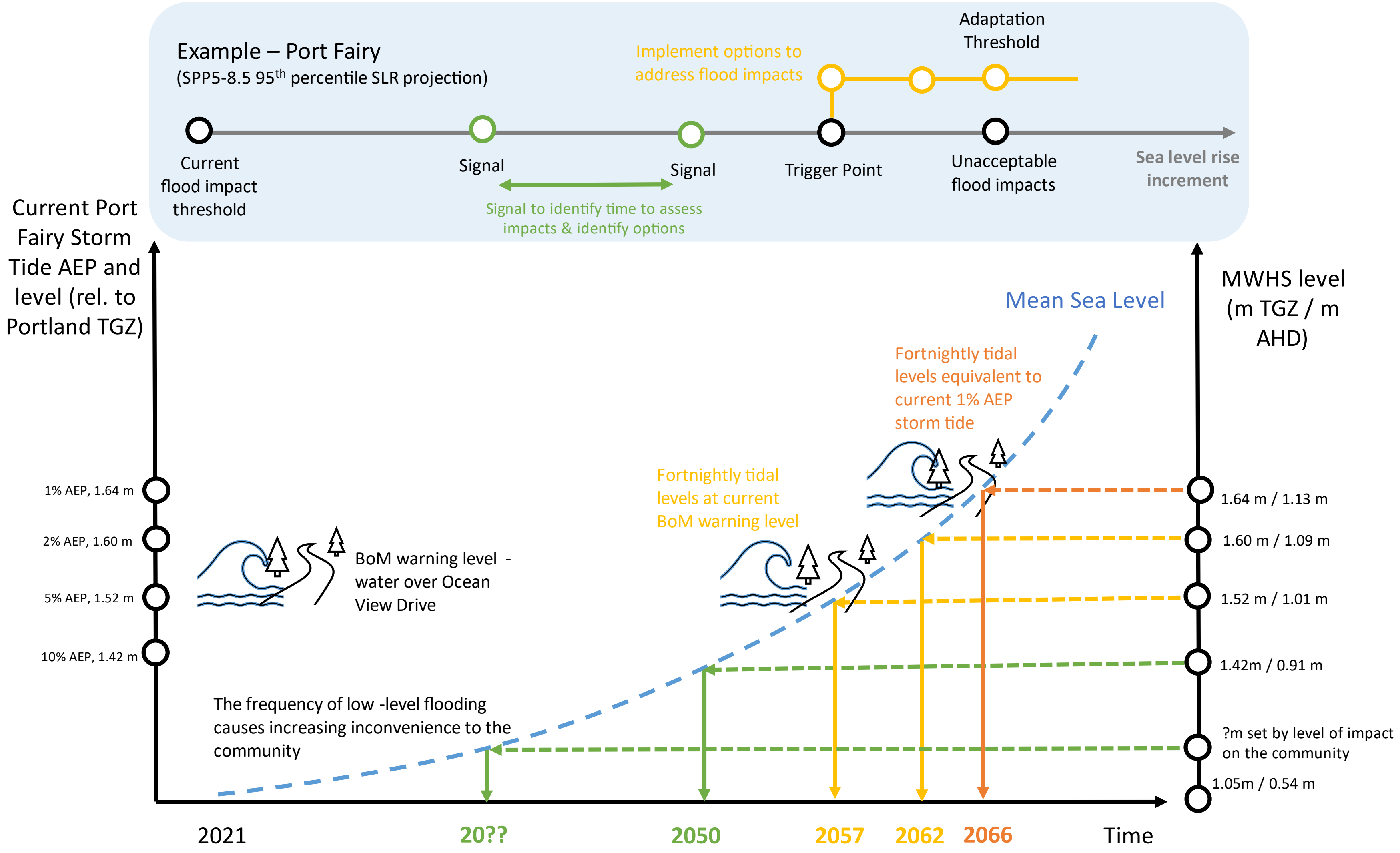

Figure 22 Example of what an impact-based adaptation pathway approach might look like for Port Fairy

5.5. **Monitoring and Review**

This report presents thresholds, triggers and related signals based on current information. They must be reviewed and modified regularly as part of the pathways approach. Mean sea level changes should be reviewed periodically, using a sea level trend report. The BoM produces monthly sea level trend reports which could be aggregated into such a report. The reporting frequency should be linked to the predicted time frame associated with the earliest signal, trigger, or threshold.

As a starting point, it could be linked to the IPCC report cycle (in the order of 6 to 7 years), or when there has been a significant revision of the climate change model predictions, for instance the IPCC 6th Assessment report when the SSP5-8.5 low confidence scenario was introduced. This aligns well with Action 4 within the draft Marine and Coastal Strategy (DELWP, 2021).

As time progresses and we move closer towards some of these threshold values, it is likely that the frequency of these reviews will need to be increased in response to increasing rate of change in mean sea level.

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