Economic Impacts from Sea Level Rise and Storm Surge in Victoria, Australia over the 21st Century

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A technical report prepared for the Victorian Marine and Coastal Council (VMaCC), with support from the Department of Environment, Land, Water and Planning (DELWP) and Life Saving Victoria

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Climate Risk Pty Ltd
Sydney, New South Wales

THE UNIVERSITY OF MELBOURNE

VICTORIAN MARINE & COASTAL COUNCIL

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Life Saving Victoria

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A TECHNICAL REPORT PREPARED FOR THE VICTORIAN MARINE AND COASTAL COUNCIL (VMaCC), WITH SUPPORT FROM THE DEPARTMENT OF ENVIRONMENT, LAND, WATER AND PLANNING (DELWP) and LIFE SAVING VICTORIA

CENTRE FOR ENVIRONMENTAL AND ECONOMIC RESEARCH (CEER)

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Highlights

- Using very large dimensional spatial and economic analysis, and two different approaches, the University of Melbourne (UoM) and Climate Risk Pty Ltd modelled the physical damages and potential economic costs of sea level and storm surge on Victoria's bay, coastal and marine areas. Results were obtained for the years 2040, 2070 and 2100 and indicate the top 40 subregions that would be affected from the impacts of inundation from global warming.

- Using the UoM approach, estimated annual economic losses to 88 different land use classifications (LUCs), including current and future residential and commercial assets, conservation areas, infrastructure, parks, and industrial and agricultural areas, for 132 subregions in Victoria, result in present value losses of over $337 billion in 2100, or 2.68% of projected GSP in Victoria. (Comparable losses in real GSP in Victoria from COVID-19 drawn from Victorian Budget May 2021 documents are estimated to be 2% in the 2020-21 financial year.) Damages from sea level rise and storm surge in 2100 are almost 10 times larger than in 2040 and losses in 2070 are almost 4 times larger than 2040.

- The UoM results also show considerable variability in damages across subregions and LUCs with physical and dollar damages to reserves and conservation areas alone nearly 40% of the total in 2100. Areas near Geelong, West of Melbourne and in South Gippsland are especially impacted. Losses in residential areas, including damages to residential land and vacant residential sites, occur largely (but not solely) in Port Phillip and East of Melbourne and the bulk of commercial damages are in Docklands and Southbank.

- An additional case study for sea level rise and storm surge impacts on wetlands potentially adds up to another \$46.05 to \$104.92 billion in losses in 2100.

- Focusing on current residential and commercial properties, along with key infrastructure, the Climate Risk approach shows that over 151,000 properties are designated as under 'high risk' in 2100, with over 333,000 properties exposed to at least some damage from inundation. Total losses are projected to force a correction to the total market value of the property portfolio in Victoria, showing a 3.7% in loss in 2100 or (roughly) more than \$104 billion (assuming no growth in asset values over time).

- Both the UoM and Climate Risk approaches indicate that although the estimated dollar damages may vary, depending on underlying assumptions, the relative impacts from inundation by subregion will likely remain. It calls for the review and to potentially extend local planning and development guidelines to ensure future at-risk areas are either avoided or adapted (where possible), to accommodate bay and coastal inundation.

1. Summary

Rising sea levels and more frequent and dramatic storm surge and flooding due to global warming will continue to impact bays and the coastal areas of Victoria this century, causing damage to residential and commercial properties, infrastructure, agricultural production, roads, beaches, and a host of public and environmental assets. Without substantial and rapid emissions reduction, IPCC (2021) indicates a sea-level rise (SLR) of up to 1.1 metres globally by 2100 and Kirezci et al. (2020), using base and extreme case scenarios, projects that the extent of SLR for the Victorian coast alone could be as high as 1.5–2.5 meters in 2100, depending on the climate change scenario. Many of these impacts will (or at least may) be irreversible and they will certainly invoke a host of adaptation measures, from the use of natural and manufactured barriers at the coastline to basic retreat from coastal areas.

Using two different and large dimensional spatial modelling approaches, one developed by the University of Melbourne, in conjunction with colleagues at the Australian National University and the University of Tasmania, and one by Climate Risk Pty Ltd, this report estimates the physical and economic impacts of coastal sea level rise and storm surge across multiple regions and land use classifications (LUCs) in Victoria.

The University of Melbourne (UoM) results are obtained for a sea level rise of 20, 47 and 82 centimetres in 2040, 2070 and 2100, with assumed realised storm surge increases of 6%, 13%, and 19% respectively, based on Department of Environment, Land, Water and Planning (DELWP) spatial layers, with supporting data from the Au stralian Bureau of Statistics (ABS) and other data sources, across 132 subregions and 88 LUCs. Storm, surge impacts are assumed to be realised in each year 2040, 2070 and 2100, taken separately. Climate Risk results are generated for up to a 1.5m sea level rise from now to 2100 using the 'Climate Risk Engines' (https://www.climaterisk.com.au/) spatial analysis for 3.8 million potentially exposed properties (concentrating here on existing residential and commercial buildings and critical infrastructure only).

The results for both physical and economic damages from sea level rise and storm surge, across a variety of metrics, are potentially substantial in scale.

For the case of no discount rate applied to future damages from sea level rise and storm surge (SLR/S) and assuming that the growth in real asset and land values over time matches the projected growth in Victorian Gross State Product (GSP) (roughly 2% per year), the UoM approach gives the following estimated economic losses from the spatial layers in 2040, 2070 and 2100, averaged across the years, in tabular form as:

Estimated Damages from SLR/S (% of GSP) in 2040, 2070 and 2100 in Victoria as Average Per Year Losses, with Average GSP for Current (Non-Discounted) Dollar Values and Assumed Growth in Land/Asset Values and GSP (Base Year 2020)

	SLR/S Costs (avg/yr) *$billion*	GSP VIC (avg/yr) *$billion*	Loss from SLR/S as % of GSP
2040	9.44	547.69	1.73
2070	14.77	718.06	2.06
2100	23.66	883.24	2.68

for an assumed 50% economic loss (as a weighted average across damages from storm surge and sea level rise, linearly scalable) in asset and land values with inundation.[1] Treating each spatial layer at 2040, 2070 and 2100 as separate 'experiments', and forming average yearly damages from SLR/S based on estimated damages in 2040, 2070 and 2100, thus gives average losses of $9.44 billion per year to 2040, $14.77 billion per year to 2070 and $23.66 billion per year to 2100. Using this approach, cumulative dollar damages in 2040, 2070 and in 2100, from 2020 forward, are thus $198.24, $753.27 and $1,916.46 billion. The nearly $1.92 trillion in damages in 2100 is almost 10 times larger than in 2040. Damages in 2070 are almost 4 times larger compared to 2040. More precisely, the proportional losses for (2040, 2070, 2100) are (1, 3.78, 9.66), The table also reports projected average values/yr for GSP and indicates percentage losses from SLR/S, again drawn directly from damages in the spatial layers in the years 2040, 2070 and 2100, as 1.73%, 2.06% and 2.68% as a proportion of state GSP.

Along with economic damages from SLR/S as indicated above, it is also important to recognise the extent of the potential physical damage. For 2100, for example, more than 75 thousand residential and commercial properties are potentially impacted, along with area land losses for (broadly defined) residential, commercial and industrial LUCs of over 45 thousand hectares, including area losses in residential land (defined with no buildings of

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[1] For a current residential property, for example, this amounts to an average replacement cost (which varies considerably across the 132 subregions and in the UoM model framework, given differing market values) of $360K, for a market value of $720K, the latter roughly consistent with state-wide averages given in ABS (2020c), assuming no discount rate and no growth in asset and land values over time. It is important to note that the LUCs used in this report are much broader than just residential properties, and include more than just replacement costs, concentrating instead on economic value losses to residential areas (existing housing and residential land and vacant residential sites), infrastructure, commercial, industrial and agricultural land holdings and environmental and public assets across the 88 LUCs.

value), vacant residential sites and commercial lands. The potential damages to reserves alone (not counting wetlands) may impact over 144 thousand hectares.

With a 5% discount rate at each time step from baseline to 2040, 2070 and 2100, given average incremental damages each year, and the same assumed increase in land/asset prices and state GSP, along with the 50% (weighted average) economic loss in asset and land values with inundation, the 'present value' (PV) of cumulative damages from SLR/S in tabular form is given by:

Cumulative Economic Damages for SLR/S in Victoria with a 5% Discount Rate and Assumed Growth in GSP and Land/Asset Values for 2040, 2070 and 2100

Year	Total PV of SLR/S Costs *\$billion*	Total GSP VIC *\$billion*	Loss from SLR/S as % of GSP
2040	122.78	7,082.47	1.73
2070	237.40	11,524.27	2.06
2100	337.82	12,597.70	2.68

or \$122.78, \$237.40, and \$337.82 billion in 2040, 2070, and 2100. Damages to residential properties and vacant residential land and residential sites alone are \$27.98 billion in 2040, \$72.93 billion in 2070 and \$94.86 billion in 2100. The table also reports cumulative values of discounted GSP and the same ratio (as in the non-discounted case) of damages from SLR/S to GSP of 1.73% (2040), 2.06% (2070) and 2.68% (2100). In other words, since the growth in real asset/land values is assumed to be the same as the growth in state GSP – which is a typical assumption — the percentage losses from SLR/S in both tables are the same and do not depend on the chosen discount rate (zero or otherwise).

Overall, there is considerable variability in damages, both across the regions and subregions and LUCs. For example, both physical and dollar damages to reserves (and conservation areas) are considerable, with more than three times the damage in hectares compared to residential, commercial and industrial LUCs combined for 2100. With a 5% discount rate, cumulative PV or discounted dollar damages here alone are more than \$130 billion from now to 2100 or approximately 38% of the total damages for that year. Damages across regions and subregions are especially variable, with considerable PV damages to reserves (and conservation areas) in the Geelong, West of Melbourne and South Gippsland regions, and the Werribee – Point Cook, Foster and Wilsons Promontory ABS SA 2 subregions.

In terms of economic damages to residential areas, including losses in residential land (with no buildings of value) and vacant residential sites, Port Phillip and East of Melbourne regions dominate. The bulk of commercial damages occur in Melbourne, especially in Docklands and Southbank, and the sites associated with water treatment facilities in Werribee are especially vulnerable, although utilities in the Geelong region are also greatly impacted.

The UoM approach also conducts a separate case study for the damages to wetlands and mangroves from SLR/S. Although there is some unavoidable (but limited) overlap in the spatial layers, with a 5% discount rate, this gives an additional PV cumulative loss from SLR/S from now to 2100 ranging from \$46.05 billion to \$104.92 billion.

In the context of the UoM report, these dollar amounts are potentially seen as conservative estimates for six reasons: (1) The increase in global sea levels may be more than 0.82m in 2100 (IPCC, 2021). This will invoke additional damages. (2) Although relative impacts across LUCs are unlikely to vary, real land and asset prices may grow faster than state GSP (i.e., 2%/yr) over the next eighty years so any damage from inundation will be more highly valued. (3) Our estimated land and property values may be lower than median prices for some subregions. (4) The assumed (weighted) loss of economic value of 50% from SLR/S — noting that economic value losses are generally much larger than physical damages — may understate damages or lost property values from inundation, especially so when a land area or property is permanently covered in water, or known to be subject to storm surge. (5) Since wetlands are a primary environmental asset, with intergenerational attributes, it would be typical to evaluate future losses with a discount rate much lower than 5%. We leave the discount rate unchanged to allow for comparability; and (6) Heritage properties and cultural and traditional values are not included, and the explicit impacts of coastal erosion are not estimated.

That said, for added accuracy, more work needs to be done on the precise micro-impact of SLR/S on land and property values, especially those that are also subject to normal physical and economic depreciation over time, for each LUC and each specific asset across all 132 regions, as well as forming more accurate estimates of SLR/S damages on wetlands. We take both of these aspects as the subject for future research.

Using the Climate Risk approach, with more limited LUCs, the number of properties exposed to at least some damage from coastal inundation is 174,409 in 2040, 199,331 in 2070 and 333,470 in 2100. Those properties designated as high risk increase from 33,205 in 2040 to 87,019 in 2070 and 151,755 in 2100.

The Climate Risk approach also adds in significant estimates of 'Total Technical Insurance Premiums' (TTIP) as the average annual losses for all hazard impacts combined and, given their uncertainty measures, an important distinction between 'Value at Risk' and the number of 'High Risk Properties' in Victoria. The approach assumes a state-wide average replacement value of $320K with a market value of $740K for residential properties, based on averages for the Victorian property market. Damages are some fraction of replacement value depending on the percentage of the property at risk.

With base year 1990, Climate Risk shows that the total cost of damage to buildings (only) for Victoria (shown through the Technical Insurance Premium or T(otal)TIP) is expected to increase to to $2.5 billion in 2040, $15 billion in 2070 and $39 billion at the end of the century (assuming a replacement cost of $320,000 per property).[2] Using a more broad level of damages to residential property market values, over and above basic replacement costs from direct damages, the Climate Adjusted Value (CAV) provided by Climate Risk in the year 2040, 2070 and 2100 gives losses of $18.06 billion, $51.62 billion and $104.06 billion

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[2] Assuming an increase in residential asset/land values of roughly 2% per year, for comparability to the UoM approach, gives cumulative damages of $236.42 billion in 2100. Losses measured by the Climate Adjusted Value (CAV) to follow are $517.48 billion in 2100 with the same assumed growth in asset values.

respectively (base case), with no assumed increase in asset values over time. Proportional losses for (2040, 2070 and 2100) are (1, 2.85, 5.57). If the total market value of the property portfolio is worth almost $2.9 trillion in Victoria, the CAV is projected to force a correction to the portfolio, losing (roughly) 0.6% in 2040 1.8% in 2070 and 3.7% in 2100 in value for the state as a whole.

Both the Climate Risk and the University of Melbourne approaches also list the top 40 sub-regions impacted by SLR/S. The ordering varies somewhat since Climate Risk concentrates on existing residential and commercial property values in this listing, whereas the University of Melbourne approach uses a broader set of LUCs, ranging from infrastructure to agricultural land to reserves and conservation areas. In the University of Melbourne ranking, the top 40 regions account for roughly 78% of the total cost of SLR/S to Victoria, although this can be somewhat misleading. Major losses in wetlands and ecosystem services are in South Gippsland and Eastern Victoria, for example, and although total dollar amounts from the damages from SLR/S may be relatively small in some regions, the percentage loss to the local economy can be very large.

The combined report also includes a limited analysis of adaptation measures for selected areas along the coast and, finally, a comparative measure of the damages from global warming in Victoria as a whole (many of which will impact coastal communities) from losses in agricultural and labour productivity through heat stress from rising temperatures.

Differences in dollar damages between the Climate Risk and University of Melbourne approaches amount to three key factors. First, to reiterate, the Climate Risk approach uses state-wide average property values. The University of Melbourne approach uses more localised, sub-regional measures of market values for asset and land values. For areas in and around Melbourne or properties near the coast with water views, this matters a great deal. Second, as indicated above, the UoM approach uses a much broader set of LUCs (even for residential and commercial properties and land areas) and does not focus solely on the replacement of damaged or existing assets. The Climate Risk approach, in other words, in terms of TTIP, largely considers damages to existing residential and commercial buildings only, not losses in land values, residential land (with no buildings of value) and vacant residential sites, or losses in reserves, conservation areas and a host of other assets. Including residential land and vacant residential sites alone, as distinct from existing residential housing, adds considerable damages to the UoM results. Third, the Climate Risk approach uses current values only and assumes no increases in asset values or land prices over time.

The two approaches, however, do approximately line up in terms of physical damages, as long as LUCs are (greatly) restricted in the UoM approach to be comparable and sea level rise in 2100 in the UoM framework (0.82m) is compared to the 2070 value (0.84m) used by Climate Risk. For UoM, restricting the LUCs to limited and existing residential and commercial properties results in physical damages to 80,090 properties in 2100. For Climate Risk, the number of high risk properties in this classification is (as indicated) 87,019 in 2070.

Overall, whatever metric is used, the UoM approach or the Climate Risk approach, the economic damages from SLR/S to Victoria indicated in this report are more than enough to trigger considerable financial instability for many coastal communities and the State of

Victoria itself, not to mention the potential loss in life, and damages to food, water supply and environmental assets from SLR/S, many aspects of which are not accounted for in our calculations.

Going forward, the results highlighted in this report invoke at least three recommendations. First, it is desirable to use the most up-to-date climate risk and hazard data to continuously assess risks to assets. For example, the spatial layers used in the DELWP data set with a 0.82m (2.69 feet) SLR in 2100 — although this data has (advantageously) a much broader set of LUCs compared to the Climate Risk approach — will likely underestimate potential damages in the future, even with the assumed storm surge impacts included. Second, it seems appropriate to further develop community awareness and outreach programs to raise coastal inundation risk awareness, especially within the identified at-risk subregions and suburbs. Third, it seems incumbent on governing authorities to review and potentially extend local planning and development guidelines to ensure future developments in at-risk areas are either avoided, designed to accommodate risk and/or adapted to include increased floor heights, floods and SLR/S overall. There are plans already in place (e.g., Melbourne Water (2017)), but these may need to be modified or further extended. Adaptation measures are particularly important given that sea levels will continue to increase for some time, even (if or) after global greenhouse gas concentrations have been stabilised, thus indicating that damages from coastal inundation will occur in bay and coastal areas regardless of which climate change scenario is applied. This last point is especially relevant for the UoM modelling, since many of the potential damages going forward are to vacant residential and land sites. Whether these are in fact developed or should be is an open question for many areas subject to SLR/S.

2. Introduction

Recent decades, in particular, have witnessed significant increases in global warming due to the rapid growth of greenhouse gas emissions (GHG), accelerating global SLR. Given 93% of the excess heat resulting from GHG has been absorbed by the oceans, due to faster-melting glaciers and polar ice sheets and the thermal expansion of ocean water (IPCC, 2021), global SLR which increased at 15 centimetres or 1.5 millimetres per year in the 1900s, has now climbed to 3.1 millimetres per year since 1993 (Australia Academy of Science (2019), Resilience (2019), and IPCC (2014)). An increasing trend of ocean warming and loss of mass from glaciers and ice sheets will cause global SLR and coastal extremes (e.g., storm tide surge) to continue increasing throughout the 21st century (IPCC, 2021).

Coastal areas are primary locations for populations, communities and native species, facilitating vital social-economic activity for cities, ports, tourism, agricultural production and a host of environmental and ecosystem services. Currently, roughly 44% of the world's population lives within 150 kilometres of the coast (USES, 2020).

Based on global models of the tide, storm surge, SLR and flooding for projections of coastal impacts over the coming century, Kirezci et al. (2020) estimated that for the case of no coastal protection or adaptation, with emissions scenario RCP8.5, there could be a 48% increase in the world's land area impacted from inundation and flooding, affecting an additional 52% of the global population and 46% of global assets by 2100. The comparable percentages at RCP4.5 are 33%, 36% and 32%. Another study indicates that SLR could cost the world economy in 2100 a massive $14 trillion a year (or 17.2% of current global GDP equivalent) if Paris climate targets are not met (Jevrejeva et al., 2019).

In Australia, about 85 percent of Australia's population lives close to the coast and the nation's major cities (Melbourne, Brisbane, Sydney, and Perth) are all positioned in coastal regions. Many of Australia's coastal plains are already lower than the current high tide level, making them vulnerable to extensive flooding with increases in sea levels and storm surge (Australia Academy of Science, 2019). The consequences of sea level rise and storm surge could be substantial, including coastal erosion, salt water intrusion, loss of agricultural and other lands with inundation, harm to coastal ecosystems, water resources and human activities, and considerable damage to infrastructure, residential and commercial properties, streets, transport, power lines and telecommunication networks (Climate Council of Australia, 2020).

In this report, the focus is on Victoria, a state in the south-east of Australia with a land area of 237,659 km^2 and 6.69 million people, making it the most densely populated state in the nation (Department of Environment, Water, Land and Planning, 2020). Bounded by Bass Strait to the south, the Great Australian Bight portion of the Southern Ocean to the southwest, and the Tasman Sea to the south-east, Victoria's beaches and coastlines stretch for almost 2000 kilometres (ABS, 2020*e*).

Using two different and large dimensional spatial modelling approaches, one developed by the University of Melbourne and one by Climate Risk Pty Ltd, this report estimates the physical and economic impacts of coastal sea level rise and storm surge across multiple regions and land use classes (LUCs) in Victoria. Results are obtained for 2040, 2070 and 2100 for a sea level rise of 20, 47 and 82 centimetres in 2040, 2070 and 2100, with assumed and realised storm surge increases of 6%, 13%, and 19% respectively, based on Department of Environment, Land, Water and Planning (DELWP) spatial layers as used by the University of Melbourne across 132 subregions and 88 LUCs (aggregated to 10 for reporting purposes); and for up to 1.5m SLR from now to 2100 using the Climate Risk 'Engines' spatial analysis for 3.8 million potentially exposed properties (concentrating here on residential and commercial buildings and critical infrastructure). The report also provides results for the top 40 most impacted regions, various case studies on adaptation measures and estimates of the non-market values of the damages to wetlands and ecosystem services from sea level rise and storm surge.

The report is structured as follows. Section 3 presents the approach used by the University of Melbourne and includes cases studies on damages to wetlands and ecosystem services from sea level rise and storm surge, along with an adaptation case study for the use of natural barriers against sea level rise and storm surge in five different and specific locations along the Victorian coast. Section 4 presents the Climate Risk approach for damages from storm surge and sea level rise to properties in Victoria, reporting against a number of different metrics, and includes (proxy) adaptation case studies for Bellarine Peninsula/Barwon Heads, Wyndham, Williamstown, Hasting and Phillip Island. Section 5 concludes and the Appendix collects some tables and offers a summary of the macroeconomic impacts of climate change in Victoria, as a means of comparison and a way of underpinning projections of state GSP used in the University of Melbourne approach.

3. The University of Melbourne Approach: Damages from Sea Level Rise and Storm Surge in Victoria to 2100

Using a large dimensional, high speed computational platform, the approach to sea level rise and storm surge (SLR/S) damages for Victoria used by the University of Melbourne (UoM) relies on projected SLR/S for 2040, 2070, and 2100 in the Victorian Coastal Inundation Dataset from the Department of Environment, Water, Land and Planning (2020). This is a digital dataset consisting of multiple spatial layers modelling the extent of land subject to coastal inundation due to projected sea-level rise and storm surge to 2100. Based on Department of Environment, Water, Land and Planning (2020), sea level rise was projected to increase by 20, 47 and 82 centimetres at 2040, 2070 and 2100, respectively, with assumed and realised storm surge increases of 6%, 13%, and 19% in 2040, 2070, and 2100, taken seperately.

In terms of geographic regions, this UoM study projects the physical and economic damages from SLR/S for 132 coastal SA2 level regions based on Australian digital data (ABS, 2020*f*), belonging to 23 Local Government Areas (LGAs). Sources for properties by regions is based on ABS (2020*b*), City of Melbourne (2020*b*), and Department of Environment, Water, Land and Planning (2020). For reporting purposes only, results are aggregated for these 132 spatial sub-regions — from the large dimensional spatial layers — into eight specific zones. These eight zones are located from the west to east, for Zone 1 (Western Victoria), Zone 2 (Geelong), Zone 3 (West of Melbourne), Zone 4 (Melbourne City), Zone 5 (Port Phillip), Zone 6 (East of Melbourne), Zone 7 (South Gippsland), and Zone 8 (Eastern Victoria). Table 1 indicates the SLR/S regions and the two levels of sub-regions used in this work. Figures 1 and 2 provide illustrations drawn directly from the spatial layers for SLR/S impacts for four selected regions of the Victorian coast in 2100 based, again, on the digital data set provided by the Department of Environment, Water, Land and Planning (2020)).

Table 1: SLR/S Regions and Sub-Regions in the UoM Model

SLR Region	**Sub_Region Level 1**		**Sub_Region Level 2**	
	Name	No	Name	No
Zone 1	Glenelg - Southern Grampians	5	Glenelg, Portland	8
	Corangamite - South		Corangamite - South	
	Colac		Otway	
	Surf Coast		Warrnambool - North & South	
	Moyne		Moyne East and West	
Zone 2	Geelong	1	Bannockburn, Golden Plains - South, Winchelsea	20

Table 1 – continued from previous page

			Belmont, Corio - Norlane, Geelong, Geelong West Grovedale, Highton, Lara, Leopold, Newcomb – Moolap Newtown, North Geelong, Clifton Springs, Lorne – Anglesea, Ocean Grove - Barwon Heads, Portarlington, Point Lonsdale – Queenscliff, Torquay	
Zone 3	Hobsons Maribyrnong Wyndham	3	Altona, Altona Meadows, Altona North, Newport, Seabrook, Williamstown, Braybrook, Footscray, Maribyrnong, Seddon – Kingsville, West Footscray – Tottenham, Yarraville, Hoppers Crossing – North, Hoppers Crossing – South, Laverton, Tarneit Truganina, Werribee – South, Wyndham Vale, Point Cook – East, North and South, Werribee – East and West	24
Zone 4	Melbourne	1	Carlton, Docklands, East Melbourne, Flemington Racecourse, Kensington, Melbourne, North Melbourne, Parkville, South Yarra – West, Southbank, West Melbourne	11
Zone 5	Port Philip	1	Albert Park, Elwood, Port Melbourne, Port Melbourne Industrial, South Melbourne, St Kilda, St Kilda East	7
Zone 6	Bayside Kingston Cardinia Casey Frankston Mornington	6	Beaumaris, Brighton, Brighton East, Cheltenham - Highett (West), Hampton, Sandringham - Black Rock, Aspendale Gardens, Braeside, Carrum - Patterson Lakes, Chelsea – Bonbeach, Chelsea Heights, Cheltenham - Highett (East), Edithvale – Aspendale, Mentone, Moorabbin – Heatherton, Moorabbin Airport, Mordialloc – Parkdale, Koo Wee Rup, Cranbourne South Pearcedale - Tooradin, Carrum Downs, Frankston, Frankston North and South, Langwarrin, Seaford, Dromana, Flinders, Hastings – Somers, Mornington, Mount Eliza, Mount Martha, Point Nepean, Rosebud – McCrae, Somerville	35

Table 1 – continued from previous page

Zone 7	South Gippsland French Island Phillip Island Bass Coast	4	Foster, French Island, Phillip Island, Wilsons Promontory, Wonthaggi - Inverloch	5
Zone 8	Gippsland - East	2	Bairnsdale, Lake King, Lakes Entrance, Orbost, Paynesville, Longford - Loch Sport, Yarram	7
	Total No of Sub Regions	**23**		**132**

Source: ABS (2021).

Figure 1: SLR and Storm Surge in Example/Selected Coastal Areas in 2100

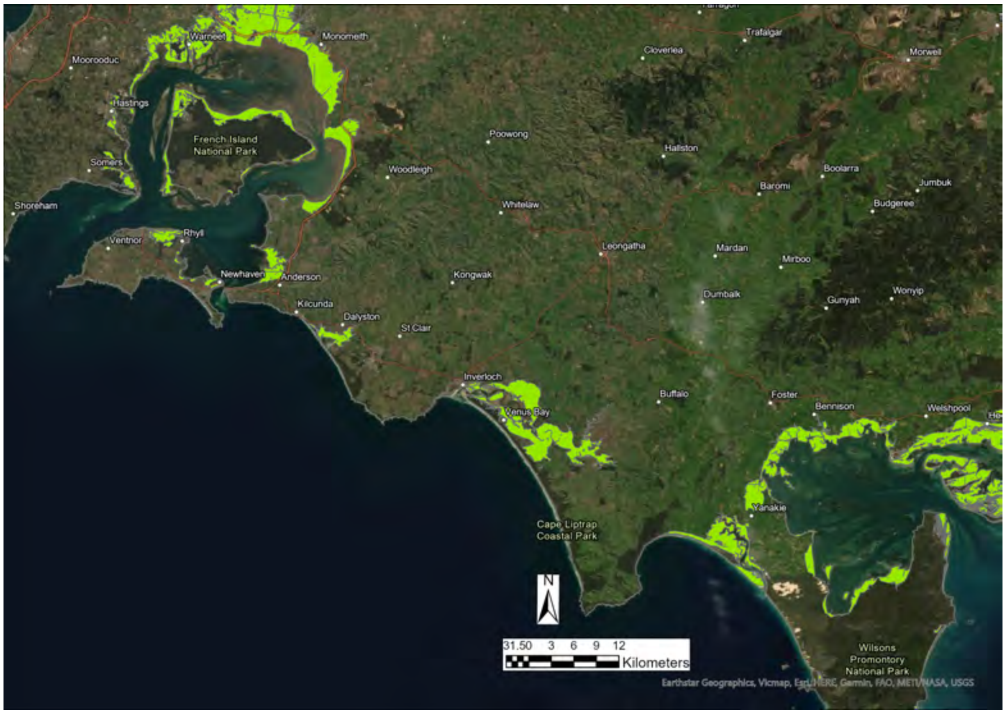
(a) Zone 1: Western Victoria

(b) Zone 3: West of Melbourne

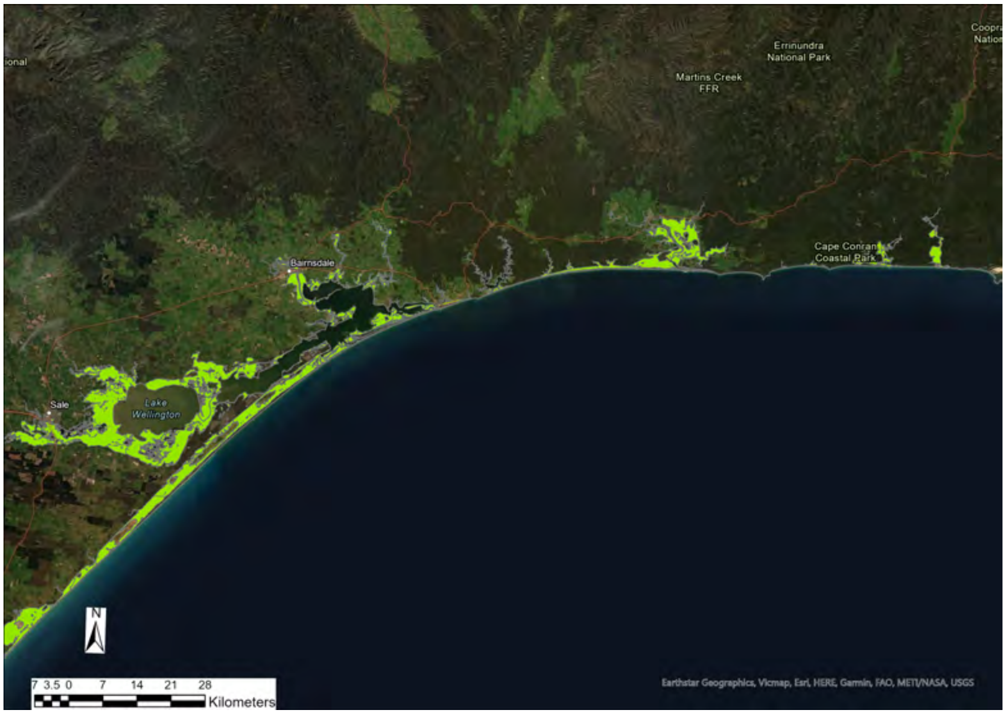
Source: Department of Environment, Water, Land and Planning (2020). (Note change in scale.)

Figure 2: SLR and Storm Surge in Example/Selected Coastal Areas in 2100

(a) Zone 7: South Gippsland



(b) Zone 8: Eastern Victoria



Source: Department of Environment, Water, Land and Planning (2020). (Note change in scale.)

3.1. Modelling Approach and Data Sources

A number of different measures for the economic damages from sea level rise and storm surge are provided in this work, over different time periods and with different assumptions, depending on whether a discount rate is used, or not. Based on spatial data from the Department of Environment, Water, Land and Planning (2020) (DELWP) for Victoria, physical and economic damages are classified across 88 sub-sectors and aggregated (for reporting purposes) into ten sectors of land use: (i) residential (LU1); (ii) commercial (LU2); (iii) industrial and manufacturing (LU3); (iv) quarries (LU4); (v) agriculture (LU5); (vi) infrastructure (LU6); (vii) education and public facilities (LU7); (viii) parks and outdoor areas (LU8); (ix) reserves (LU9); and (x) unidentified land use by private sector (LU10). The 10 LUCs are further disaggregated in the UoM model into 30 separate classifications. The 10 LUCs and 30 sub-categories are reported in Table 2. The details for the 88 sub-sectors are provided in the Appendix, Table A1. Separate case studies for the economic damages to wetlands and environmental assets are also obtained in this section of the report, along with a 'natural barriers' adaptation case study.

There are a number of key assumptions to highlight at the outset, including:

- Economic damages from SLR/S are reported in both current or non-discounted dollars (in summary form) and with a 5% discount rate (in extensive form). A brief primer on discounting is provided below.
- The UoM report does not assume or explicitly specify any adaptation measures, save for a case study on mangroves as a natural barrier.
- The DELWP spatial layers allow for projections of sea level rise at 2040 (.20m), 2070 (.47m) and 2100 (.82m), with assumed and realised 6% (2040), 13% (2070) and 19% (2100) storm surge. These represent three 'endpoint' measures where each endpoint is treated as a separate 'experiment'. The UoM approach thus runs three different spatial models. However, given the endpoints, damages from SLR/S accrue more or less continuously over time and when discounting is used for these future damages it is inappropriate to simply discount dollar amounts at each endpoint. This would understate damages, in other words, given that the discount factor is applied only at the endpoint. Instead, a linear incremental increase (i.e., the average annual increment) in damages to each endpoint over time is assumed, given a baseline, with damages at each annual time-step properly discounted. Discounted economic damages are thus obtained for each year to a given endpoint and then aggregated for 2040, 2070 and 2100 for reporting purposes. In reality, physical and economic damages, depending on the timing and extent of SLR/S, may in fact increase more than the yearly average over time, or from year-to-year.
- The baseline increase of 0.82m in 2100 from the DELWP spatial layers is the assumed or current climate change projection for SLR/S, knowing that SLR/S is now projected to be much larger in 2100 (e.g., IPCC (2021) and Kirezci et al. (2020)). SLR/S measures in the UoM report are thus taken as conservative.

- There is no sufficiently detailed information on the extent of physical and economic damage from inundation for all LUCs, much less for all individual assets and properties. In some cases, inundation from SLR/S can result in complete loss of the value of a land parcel or property. In other cases, damages will be far less depending, in part, on adaptation measures and the extent of inundation. The UoM report assumes a loss of economic value of 50% (as a weighted average across damages from sea level rise and storm surge, linearly scalable) from inundation — noting that economic value losses are generally much larger than physical damages (e.g., a flooded parking garage in an apartment building impacts the entire economic value of the building).[3] This may considerably understate damages or lost property values from inundation, especially so when a land area or property is permanently covered in water, or known to be subject to storm surge. Further precision would require specific knowledge of the physical and economic impacts in each region (for storm surge and sea level rise taken separately) and for each land area or property within that region. With the assumption of a 50% loss in economic value from SLR/S, damages for a residential property, for example, gives an average replacement cost (which varies considerably across the 132 regions and in the model framework given differing market values) of $360K, for a market value of $720K, the latter roughly consistent with state-wide averages given in ABS (2020*c*), assuming no discount rate and no growth in asset prices.

- Although not possible in all cases, the UoM report uses disaggregated land and asset prices from publicly available sources, at the subregion level, instead of average building replacement costs and average market and rental values, particularly state-wide averages. However, the analysis does not capture a range of uncertainty in these values and indeed the DELWP spatial layers that are used are also not calibrated with ranges of uncertainty, save for the projections on the frequency of storm surge. In general, land values are drawn from existing real estate information and average property values are estimated from both real estate information and rental values. In cases where there are no land value estimates a percentage proxy from nearby land values is used.

- In the cases where increases in *real* asset values are assumed over time the analysis follows Ng and Mendelsohn (2005) and assumes that the growth of the price of land matches the percentage change in state economic growth. No explicit assumptions are made as to whether individuals are myopic in their planning, or in how they form expectations of future asset prices (e.g., tomorrow's asset price is a simple projection of today's price), or whether they have perfect foresight on the projected impacts of SLR/S on asset and land values in the future. Recent work suggests that sea level rise and inundation risk is not capitalised into residential property values, suggesting either

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[3] The exact weighted average depends on subregion and LUC, relative to proportional impacts. For example, for a proportional impact of 25:75 from sea level rise and storm surge taken separately, with losses of 100% from permanent inundation from sea level rise and 33% (or one third) from storm surge, gives $.25 * 1.00 + .75 * .3333 \approxeq .50$ or roughly 50% in economic losses.

myopic pricing behaviour or a lack of knowledge on potential SLR/S impacts and the potential cost of adaptation in the future (Fuerst and Warren-Myers, 2021).

- The debate over the choice of discount rate, risk-adjusted or not, is ignored in the report, choosing instead to just present both undiscounted and 'present value' (PV) results for a 5% discount rate, knowing that it is not uncommon to use lower discount rates for environmental assets (Costanza et al., 2021). A 5% discount rate and growth in real asset and land values that matches the growth in state income allows for an order of magnitude comparison of percentage damage costs from SLR/S to the value of Gross State Product (GSP) in Victoria over time, given that we are also assuming that GSP grows at a certain rate to 2100. This comparison is also possible when there is no discounting and is reported below.
- Since our focus is primarily on economic damages to the value of land from SLR/S, the otherwise (ordinary) physical and economic depreciation of already existing physical assets over time is not considered, and would be difficult to specify by LUC and each specific asset for all 132 regions in any case. That said, different states of physical and economic depreciation of assets on land holdings would alter (and in many cases presumably lessen) the dollar damages from SLR/S.

Overall, to restate, the economic damages and loss of land area is based on 88 sub-categories of land use, aggregated into 10 categories (LU1-10) (see Table 2). The SLR/S damages are considered as the intersections of land and/or spatial asset characteristics and values that fall within the projected SLR/S spatial layers (Department of Environment, Water, Land and Planning, 2020) using a large dimensional GIS programming methodology.

3.1.1. The Role of Discounting

Although results for SLR/S damages are also presented without a discount rate in this report, when considering costs (and benefits) over time it is common to use a discount factor, and a specific discount rate to convert future dollar amounts into 'present values' (or 'net present value' if both benefits and costs are included). In fact, it is generally essential to discount when weighing up different alternatives with time-varying and different amounts of losses or expenditures going forward — placing the comparisons on a common footing.

The casual rationale offered by economists for discounting runs in terms of the narrative: 'Would you prefer \$100 today or ten years from now?' The natural response (supposedly) is \$100 today, since with that money one could (aside from just enjoying consumption today) invest the sum, earn a return, compounded over time by the interest rate, and thus enjoy a much larger amount of money than \$100 ten years from now. For a 10% interest rate, for example, \$100 today would be worth \$110 a year from now and (with compounding, or interest earned on principal plus interest), \$121 in year 2, \$133 in year 3 and so on, up to \$259 in year 10. In that sense, \$259 ten years from now is 'worth' only \$100 today, in 'present value' (PV) terms. Discounting thus runs backward, or converts future value (FV), to the present, so if $FV = \$100(1 + .10) = \$110$ for the one-period case, with an interest rate of 10%, PV takes on the formula $PV = \$100(1 + \delta)^{-1}$. It follows that over time, for damages (D_t) that can occur at any time period, properly discounted in that period, gives the PV formula as:

$$PV = \sum_{t=1}^{T} \frac{D_t}{(1+\delta)^t} \tag{1}$$

for discount rate δ.

The essential problem comes with the choice of the discount rate since higher rates greatly discount future damages, from sea level rise and storm surge in our case. For example, using the above formula, \$100 in damages 80 years from now is worth \$12.22 at a 3% discount rate, \$2.62 at 5% and only 6 cents at a 10% discount rate. Discounting over a long period of time, in other words, at high rates, can severely discount future damage measures (and the welfare of future generations depending on the decision context). This is fundamentally why it is common to use (lower) discount rates ranging from 1% to 4% in climate change discussions, and there is certainly a good case for lower discount rates on long-lived environmental assets. In general, different types of capital assets (built, human, social, natural) have different characteristics and contribute differently to the production of all goods and services, both directly and in terms of the ecosystem service values they generate. Although ethical and intergenerational considerations will always matter over the exact choice of the discount rate, different assets should require different discount rates (Costanza et al., 2021). In this report, this issue is set aside and 5% is taken as a base discount rate, noting that the damages to wetlands and mangroves illustrated below, for example, will be an underestimate.

One key benefit of the way that dollar damages from SLR/S are estimated below is that although specific dollar amounts may vary depending on assumptions over the discount rate, the ratio of damages from SLR/S to state GSP is itself invariant to the discount rate, given the assumption that the growth in real land/asset values is the same as the projected growth in GSP. In this setting, in other words, the choice of the discount rate does not matter.

3.1.2. Economic Damages

Economic damages ($C(K)(i,t)$) from SLR/S across all LU categories at time t in a region depends on the number, type (see Table 2), and value of the properties in the inundated area and is given by the basic formula:

$$C(K)(i,t) = \sum_{i} LU(K)(i,t) * [v_K(i,t)] \tag{2}$$

where $C(K)(i,t)$ is the economic damage or cost for LU category $K = 1...10$, for attribute or subtype i in each LU category, across all of the units in a subtype, and $v_K(i,t)$ is the loss in value per subtype i in each LU category K, across all units in that subtype (Table 2), at each point in time, 2040, 2070 and 2100, taken separately. When a discount rate is used, the formula becomes:

$$C(K)(i,t) = \sum_{i} \sum_{t} \frac{LU(K)(i,t) * [v_K(i,t)]}{(1+\delta)^t} \tag{3}$$

where the value $(1+\delta)^t$ thus applies a discount factor at each time t for discount rate δ. In short, for equation (3), the relevant measure is the number of land parcels or properties times their value lost at time t, for each subtype i, discounted (as indicated above in the set of assumptions) to the present. Total losses are then summed over all regions and LU categories and sub-types, as reported, in aggregated form, for each Zone 1 through 8.

There are 5 major subtypes of residential properties (or LU1, Table 2): (LU11) separate houses; (LU12) semi-detached houses and townhouses; (LU13) apartments, flats, and units; (LU14) residential land; and (LU15) vacant residential land (without roads or supporting infrastructure). The losses in residential property values, $v_1(i,t)$, for example, are given by the value of that property or land parcel, either directly or as proxied by the relationship between average rentals and prices in that specific area or region (see the section on data sources and parameters below). LU14 and LU15 pick up the potential growth in community housing over time, at least in terms of the (potential) loss of land value from these LUCs.

There are 4 major subtypes of commercial properties (LU2, Table 2): (LU21) mixed commercial use, (LU22) hotels, motels, apartment hotel complexes, pubs, taverns, clubs, and restaurants, (LU23) office premises, outlet, garages, service stations, public health facilities, and (LU24) commercial lands; and 3 major subtypes in industrial and manufacturing properties (LU3, Table 2): (LU31) industrial sites, general-purpose factories, industrial complexes, (LU32) warehouses, and (LU33) oil and gas manufacturing. Quarries (LU4, Table 2) is designated by a single category for fields and manufacturing, whose value is drawn from basic land prices in the area; and agriculture (LU5, Table 2) is simply given by farming and grazing.

Infrastructure (LU6, Table 2) has 10 sectors or subtypes: (LU61) transport (road, rail), (LU62) gas transmission lines, (LU63) electricity transmission, (LU64) electricity distribution and lines, (LU65) hazardous/toxic material storage, (LU66) sewerage plant and stations, (LU67) sewerage pipelines, (LU68) water distribution network, (LU69) telecommunication towers and aerials, and (LU610) other utility land. Education (LU71) and public facilities (Lu72) (LU7, Table 2) are defined as such; whereas parks and outdoor areas (LU8, Table 2) includes museums, galleries and park (LU81) and outdoors (LU82). Reserves (LU 9, Table 2) include reserves and conservation areas and unidentified land use (LU10, Table 2) is designated for unidentified private land.

3.2. Data Sources and Parameters

In this study, as indicated, spatial estimates for the economic damages from SLR/S are applied to different land-use types following Department of Environment, Water, Land and Planning (2020) (see Table 2 and the Appendix (1), Table A1 for the full 88 LUCs). Full digital data sets are sourced from both Department of Environment, Water, Land and Planning (2020) and ABS (2020*f*). Sources for properties by regions is based on ABS (2020*b*), City of Melbourne (2020*b*), and Department of Environment, Water, Land and Planning (2020).

Placing economic values on the various LU categories and the associated damages from SLR/S is challenging, and there is incredible detail involved across the 132 regions and LUCs. In some cases direct or estimated values are readily obtainable (e.g., LU1, LU2 and LU5), in other cases proxy values must be applied. The value of residential properties, for example, are either given directly or estimated from the average rental costs in the specific area or region (ABS (2020*f*) and City of Melbourne (2020*b*)), or by median house prices in the area. Some adjustments are applied for rental costs for houses, semi-detached houses, apartments, and units based partly on Victorian real estate sources (UDIAVIC, 2019). Costs of lost land with inundation are based on the size of land areas potentially impacted by SLR/S, where land prices by region and category are drawn from City of Melbourne (2020*a*), Allhomes (2020), Real Estate of Australia (2020) and (ABS, 2020*d*). Base land use values in the area are applied to LU3, LU4, LU6 and LU7.

In general, when data or estimates are not available or appropriate, conservative estimates are used. For example, quarry land value (LU4) is taken as 20% of rural land prices. Transport or road land values (LU61) are given by vacant nearby land prices plus the average cost of road construction by km^2 (Bureau of Infrastructure, Transport and Regional Economics (BITRE), 2020). The land value for gas transmission lines (LU62), by area, is taken as 1.2 times the value of residential land. The values of electricity sectors (LU63-64), sewerage (LU66-67), water (LU646), and telecom/aerials (LU69) is taken as 1.44 times the value of residential land. The land value for public facilities (schools, churches, health care), or LU71, is assumed to be equal to 0.5 and 1.2 of land prices for rural areas and Melbourne, respectively. Where specific source or reasonable proxy data is not available, the adjusted coefficient for the commercial property values is assumed to be 2.5 times the average house price in the relevant SLR/S areas; the adjusted coefficient is 5.0 for hotels, motels, pubs, and restaurants, and 7.0 for office premises. The number of units for an apartment building (normally in Melbourne City or nearby) is estimated from UDIAVIC (2019).

In cases where there is virtually no or very limited available information for land values, an approximate measure from known prices in nearby land parcels is used – something akin to a 'hedonic pricing' scheme (Rosen, 1974). In other words, it is assumed that these 'unknown' values are influenced by their location or their nearby neighbourhood or environment. For example, the value of a park in Melbourne city would have a higher 'value' if sold in a market compared to an equivalent parcel in a rural area. We generally follow this rule for LU categories 8-10.

In some cases, for vacant and (potentially) residential land, we estimate (and test) land values by employing a measure of the cost of land preparation from raw land to built land. The details of land costs are based on Home Guide (2020). For example, clearing rocks from land typically has these cost components: \$5.53–\$9.15 per linear foot basic charge; stump width from \$67-\$130 per stump; the average price of excavation is between \$1,600–\$4,400; and land grading costs are between \$6,000 to \$10,000 per acre. For a heavily forested acreage these costs are: \$3,790 to \$6,710 upfront; and bulldozing for a 140 horsepower dozer is valued at \$568 for a half-day, \$811 for a day or \$2,310 per week (Home Guide, 2020). The costs of a facility such as a road (BITRE, 2020), plumbing, sewage, utility transmission (Septic System Australia, 2020) are also included here. In other cases, we take a simple fraction of the value of nearby land to value land parcels. The values for reserves (LU9) and unidentified lands (LU10), again opting for conservative measures, are assumed to be equivalent to 30% and 10% of the value of the nearest residential land areas respectively. More precise measures for ecosystem services from wetlands, mangroves and associated 'wetland' reserves and conservation areas are detailed in case studies below (see Section 3.5).

Example estimated coastal land values, in aggregated form and for selected LU categories, in 2020 are provided in Table 3, with Melbourne listed separately in Table 4. As indicated, the land value categories are based on Table 2 and estimated economic damages depend on the quantity of buildings, properties and other land parcels potentially lost and their associated asset or land value (using, as indicated above, a weighted average of damages from inundation from see level rise and storm surge taken separately).

The projection of Victoria's economic growth is assumed to be the same for Australia. The medium-term outlook for Australian economic growth, without pandemic COVID-19 impacts included, is based on IMF (2021), and then projected forward (roughly 2% per year) taking into account possible falls in Australian GDP and GSP growth for Victoria as indicated in the climate change (macroeconomic) modelling used for this report (see the Appendix (2)).

Table 2: Aggregated SLR/S Economic Damages or Cost Categories by Land Use in the UoM Spatial/GIS Model

Land Use Groups	**Aggregated Damage Categories in the Model**			
	LU_	Model Codes	Economic Value/Content	LU Sub-category Codes
1. Residential	LU_1=1	LU11	Separate houses	110,111,117,101
		LU12	Semi-houses, townhouses	112, 120, 121
		LU13	Apartments/flats/units	131,132,133,142,150
		LU14	Residential land	101, 108
		LU15	Vacant residential site	100, 102, 103
2. Commercial	LU_2=2	LU21	Mixed commercial use	200, 210, 212, 213, 214, 215
		LU22	Hotels, motels, restaurants, pubs	230, 240, 243
		LU23	Offices, public facilities	220, 221, 270, 271, 273, 280
		LU24	Commercial lands	202, 234
3. Industrial and Manufacturing	LU_3=3	LU31	Industrial sites	300, 310, 311, 312
		LU32	Warehouses, open areas	320, 321
		LU33	Oil & gas manufacturing	335
4. Quarries	LU_4=4	LU4	Fields & manufacturing	408, 410, 412, 461
5. Agriculture	LU_5=5	LU5	Farming & grazing	530, 546, 550, 561, 583
6. Infrastructure	LU_6=6	LU61	Transport	601, 654, 655
		LU62	Gas transmission lines	613
		LU63	Electricity transmission	624
		LU64	Electricity distribution	625
		LU65	Hazardous/toxic center	634
		LU66	Sewerage plant & station	636, 637
		LU67	Sewerage pipeline	638
		LU68	Water distribution network	646
		LU69	Telecom, aerials	694
		LU70	Utility land	600
7. Education and public facilities	LU_7=7	LU71	Education	720, 721, 727
		LU72	Public facilities	740, 742, 743, 750, 78, 780
8. Parks and Outdoor Areas	LU_8=8	LU81	Museum, galleries, parks	720, 721, 727
		LU82	Outdoors	813, 821, 822, 824, 828, 829
9. Reserves	LU_9=9	LU9	Reserves & conservation areas	90, 91, 960, 961, 972
10. Unidentified land use	LU_10=10	LU10	Unidentified private land	UPL

Source: Derived from Department of Environment, Water, Land and Planning (2020). See the Appendix (1) for the details of the full 88 land use categories.

Table 3: Example Coastal Land Values, excluding Zone 4 (Melbourne City) in 2020 (*$/hectare)*

			Land Use Category							
No	SLR/S region	Sub-region	Residential	Vacant	Industry, manufacturing	Grazing, farming	Education public areas	Museum, entertainment, gallery, parks	Outdoors	Reserves, conservation unidentified use
			LU14	LU15 Vacant	LU3, LU6	LU5	LU7	LU81	LU82	LU9-10
1	Western Victoria	Colac	4,856,360	2,220,851	5,827,632	444,170	2,220,851	809,393	485,636	242,818
		Corangamite	4,856,360	2,220,851	5,827,632	444,170	2,220,851	809,393	485,636	242,818
		Glenelg	5,816,256	2,659,819	6,979,508	531,964	2,659,819	969,376	581,626	290,813
		Moyne	2,755,608	2,188,296	3,306,729	437,659	2,188,296	459,268	275,561	137,780
		Surf Coast	8,991,037	4,111,671	10,789,244	822,334	4,111,671	1,498,506	899,104	449,552
2	Geelong	Greater Geelong	6,635,897	3,034,648	7,963,076	606,930	3,034,648	1,105,983	663,590	331,795
3	West of Melbourne	Hobsons	10,894,823	4,982,288	13,073,788	-	4,982,288	1,815,804	1,089,482	544,741
		Maribyrnong	875,599	400,418	1,050,719	-	400,418	145,933	87,560	43,780
		Wyndham	8,306,408	3,798,585	9,967,690	759,717	3,798,585	1,384,401	830,641	415,320
5	Port Phillip	Port Phillip	5,675,150	2,595,290	6,810,180	-	2,595,290	945,858	567,515	283,758
6	East of Melbourne	Bayside	9,215,017	4,214,099	11,058,020	-	4,214,099	1,535,836	921,502	460,751
		Cardinia	8,451,288	3,864,840	10,141,546	772,968	3,864,840	1,408,548	845,129	422,564
		Casey	8,138,338	3,721,726	9,766,006	744,345	3,721,726	1,356,390	813,834	406,917
		Frankston	8,461,410	3,869,469	10,153,693	773,894	3,869,469	1,410,235	846,141	423,071
		Kingston	701,372	450,000	841,647	90,000	450,000	116,895	70,137	35,069
		Mornington	6,040,844	2,762,525	7,249,013	552,505	2,762,525	1,006,807	604,084	302,042
7	South Gippsland	Bass Coast	2,739,846	1,252,953	3,287,815	250,591	1,252,953	456,641	273,985	136,992
		French Island	4,857,388	2,221,322	5,828,866	-	2,221,322	809,565	485,739	242,869
		Phillip Island	5,675,150	2,595,290	6,810,180	519,058	2,595,290	945,858	567,515	283,758
		South Gippland	3,472,332	1,587,925	4,166,799	317,585	1,587,925	578,722	347,233	173,617
8	Eastern Victoria	East Gipplands	1,534,147	701,577	1,840,977	140,315	701,577	255,691	153,415	76,707
		Wellington	1,034,636	325,176	1,241,563	65,035	325,176	172,439	103,464	51,732

Table 4: Example Land Values in Zone 4 (Melbourne) in 2020 (*$/hectare)*

No	Sub-region Level 2	**Land Use Category**							
		Resident commercial	Industry manufacturing	Road transport	Gas transmission	Infrastructure	Education, public facilities	Museum, entertainment, park, outdoors	Unidentified
		LU1-2	LU3	LU61	LU62	LU63-69	LU71-72	LU81-2	LU10
1	Carlton	49,955,043	59,946,052	51,455,043	59,946,052	71,935,262	59,946,052	8,325,841	4,995,504
2	Docklands	61,549,070	73,858,884	63,049,070	73,858,884	88,630,661	73,858,884	10,258,178	6,154,907
3	East Melbourne	29,744,093	35,692,912	31,244,093	35,692,912	42,831,494	35,692,912	4,957,349	2,974,409
4	Flemington Racecourse	29,744,093	35,692,912	31,244,093	35,692,912	42,831,494	35,692,912	4,957,349	2,974,409
5	Kensington (Vic.)	29,744,093	35,692,912	31,244,093	35,692,912	42,831,494	35,692,912	4,957,349	2,974,409
6	Melbourne City	56,153,180	67,383,816	57,653,180	67,383,816	80,860,579	67,383,816	9,358,863	5,615,318
7	North Melbourne	49,955,043	59,946,052	51,455,043	59,946,052	71,935,262	59,946,052	8,325,841	4,995,504
8	Parkville	49,955,043	59,946,052	51,455,043	59,946,052	71,935,262	59,946,052	8,325,841	4,995,504
9	South Yarra - West	49,955,043	59,946,052	51,455,043	59,946,052	71,935,262	59,946,052	8,325,841	4,995,504
10	Southbank	74,044,145	88,852,974	75,544,145	88,852,974	106,623,569	88,852,974	12,340,691	7,404,415
11	West Melbourne	49,955,043	59,946,052	51,455,043	59,946,052	71,935,262	59,946,052	8,325,841	4,995,504

3.3. Results for Economic Damages from SLR/S

Various results and tables are shown based on the assumed discount rate and growth in real asset and/or land values, conditional on given projected growth in GSP. The number of physically impacted properties and area (hectares) from SLR/S is indicated in Table 5 for selected LUCs. It is important to note that the number of physically damaged properties is increasing for all land types and zones. For residential properties alone (LU11–LU13), the total number of properties impacted by SLR increases from 5,549 in 2040 to 33,223 in 2070 and 68,312 in 2100. Damages to commercial properties (LU21–LU23) increase from 1,278 in 2040 to 6,068 in 2040 and 7,292 in 2100. Over 144,000 hectares of reserve land is lost in 2100, with 5232.7 hectares lost in 2040 and 86,496.5 lost in 2100.

The PV calculations with a 5% discount rate and growth of real asset prices or land values shows damages from SLR/S as \$122.78 billion, \$237.40 billion and \$337.82 billion in 2040, 2070, 2100 respectively (see Table 6). The PV damages for Residential Areas alone (LU1, which includes five categories, LU1–LU5) are \$27.98 billion in 2040, \$72.93 billion in 2070 and \$94.86 billion in 2100.[4]

Based on this approach we calculate: (a) the comparative projected fall in asset values from SLR/S as a percentage of projected increases in state income (or Gross State Product (GSP)) to provide an order of magnitude and (b) array the 40 most affected sub-regions (which are basically invariant to assumptions on discount rates and economic growth).

For (a), GSP for Victoria in 2018-19 was \$446.08 billion, based on ABS (2020*a*). Given our projection of economic growth at the national and state level, Table 10 shows discounted total GSP and the average percentage fall in asset/land values from SLR/S compared to GSP for 2040 (1.73), 2070 (2.06) and 2100 (2.68), using a 5% discount rate. Note, that these percentage losses in state GSP *do not* include the damages to ecosystem services to follow (see Section 3.5).

For (b), Tables 7 to 9 show the top 40 sub-regions with the highest PV of economic losses from SLR/S in 2040, 2070, and 2100, again with a 5% discount rate and assumed growth in asset/land prices. The table also indicates where the (aggregated) damages by LU classification originate. The top 40 sub-regions account for almost 80% of the total cost to Victoria from SLR/S. Indeed, total costs of the top 40 sub-regions increase from \$116.39 billion in 2040 (Table 7) to \$233.39 billion in 2070 (Table 8) and \$309.60 billion in 2100 (Table 9). Ranking by Zone from Table 6 gives Zone 3 (West of Melbourne), Zone 4 (Melbourne) and Zone 6 (East of Melbourne) as the most vulnerable.

Finally, in Table 11 the economic damages from SLR/S in current dollars are reported, with no discounting, for 2040, 2070 and 2100, assuming that the growth in asset/land values

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[4] A recent study (DCEE, 2011) estimated losses for Victoria from a sea level rise of 1.1m at (roughly) \$33 billion. However, this study uses 2008 replacement values, does not assume increases in asset and land values over time, and has very limited LUCs, concentrating on the replacement of existing residential buildings, roads, rail and light commercial buildings. Moreover, there is no measure of the value of land parcels lost (residential and commercial) or damaged, or losses to industrial, agricultural and environmental assets, among others. The report also does not appear to cover the full loss in economic values for the 132 subregions as used here.

equals the growth in state GSP. The table shows (averaged) damages from 2020 to 2040 at \$9.44 billion per year, \$14.77 billion per year to 2070 and \$23.66 billion per year to 2100, based on the economic damages that are estimated in the separate 2040, 2070 and 2100 spatial layers. When viewed in this way, the cumulative losses to 2040 are \$198.24 billion, \$753.27 billion in 2070 and \$1.916 trillion in 2100, keeping in mind that asset/land values are assumed to grow at 2% per year. The table also reports projected average values for GSP and indicates an important point. In terms of percentage damages from SLR/S, or as a proportion to state GSP, the value is 1.73% (2040), 2.06% (2070) and 2.68% (2100). Since the growth in asset/land values is assumed to be the same as the growth in state GSP, the percentage losses in both Tables 10 and 11 are the same and indeed these percentage losses are invariant to the chosen discount rate. In other words, when expressed as percentage losses to state GSP the damages from SLR/S are independent of the discount rate.

Along with economic damages from SLR/S as indicated above, it is also important to recognise the extent of the potential physical damage (see Table 5). For 2100, for example, more than 75 thousand residential and commercial properties are impacted, along with area land losses for broadly defined residential, commercial and industrial land use classifications of over 45 thousand hectares, including area losses in residential land (with no buildings of value), vacant residential sites and commercial lands. The potential losses in reserves alone (not counting wetlands) are over 144 thousand hectares. Overall, there is considerable variability in damages, both across the regions and subregions and LUCs — a point highlighted in Section 3.4.2 below.

Table 5: SLR/S Damages in Victoria by Quantity (No and Area) in the 21 Century for Selected LUCs (e.g., LU14 and LU15 for residential areas are not included, see Table 2).

Region		**Land Use Category**										
		Number properties (**No**), LU11–LU13, L22–LU23							Area (**hectares**), LU1-3, LU7-10, LU61-70			
		LU11	LU12	LU13	LU21	LU22	LU23	LU1-3	LU61-70	LU7-8	LU9	LU10
		Houses	Semi-houses	Places of units, flats, apartments	Comm others	Hotel restaurants pubs, bar	Offices health care	Residence commerce, industry	Utilities	Public parks outdoors	Reserves	Other
						2040						
1	Western Victoria	73.0	2.0	7.0	-	1.0	-	192.6	6.9	2.8	898.5	401.9
2	Geelong	2,814.0	217.0	13.0	19.0	8.0	4.0	653.1	2,604.5	751.5	3,921.6	2,651.5
3	West of Melbourne	241.0	47.0	-	1.0	-	18.0	54.3	663.2	378.1	35,726.6	1,263.5
4	Melbourne	82.0	509.0	-	1,227.0	75.0	266.0	523.8	46.1	22.9	246.6	3,975.3
5	Port Phillip	610.0	55.0	668.0	28.0	7.0	173.0	76.5	22.7	14.4	126.1	677.3
6	East of Melbourne	3,012.0	774.0	251.0	21.0	10.0	8.0	11,400.4	448.5	844.0	1,606.6	2,821.4
7	South Gippsland	462.0	13.0	-	3.0	1.0	-	110.8	148.1	24.6	27.9	460.2
8	Eastern Victoria	23.0	1.0	-	1.0	-	-	27.4	7.9	4.7	11.8	52.7
	Total	7,317.0	1,618.0	939.0	1,300.0	102.0	469.0	13,038.8	3,947.8	2,043.1	42,565.9	12,303.9
						2070						
1	Western Victoria	556.0	56.0	22.0	2.0	7.0	-	290.3	9.3	18.1	1,894.9	449.5
2	Geelong	7,050.0	775.0	64.0	125.0	57.0	20.0	2,466.9	2,920.3	976.5	8,441.2	3,590.3
3	West of Melbourne	2,672.0	428.0	20.0	27.0	11.0	112.0	261.2	1,764.7	1,841.1	71,475.4	2,499.6
4	Melbourne	615.0	1,786.0	43.0	5,439.0	846.0	835.0	4,163.9	98.3	97.0	192.7	7,336.5
5	Port Phillip	5,288.0	676.0	3,492.0	190.0	91.0	384.0	254.2	25.4	107.1	84.5	2,238.4
6	East of Melbourne	5,273.0	892.0	566.0	227.0	50.0	68.0	32,564.2	724.2	1,307.8	1,330.6	2,065.2
7	South Gippsland	1,198.0	227.0	2.0	17.0	12.0	2.0	322.0	148.9	25.4	68.8	608.7
8	Eastern Victoria	1,331.0	106.0	40.0	41.0	5.0	1.0	826.0	-	95.8	3,009.4	908.3
	Total	23,983.0	4,946.0	4,249.0	6,068.0	1,079.0	1,422.0	41,148.8	5,691.1	4,468.9	86,497.5	19,696.4
						2100						
1	Western Victoria	1,206.0	94.0	38.0	5.0	7.0	1.0	462.3	9.3	23.9	3,166.5	465.8
2	Geelong	12,853.0	1,399.0	116.0	319.0	104.0	43.0	3,492.0	3,199.6	1,219.0	14,305.0	4,308.5
3	West of Melbourne	8,471.0	1,207.0	106.0	128.0	20.0	122.0	701.0	1,866.6	2,052.8	119,139.0	6,873.6
4	Melbourne	1,671.0	2,317.0	67.0	5,823.0	1,864.0	1,007.0	4,793.0	106.2	109.9	367.2	8,507.4
5	Port Phillip	10,402.0	1,333.0	7,808.0	518.0	182.0	867.0	710.3	41.2	195.7	144.2	6,805.1
6	East of Melbourne	11,837.0	1,797.0	655.0	427.0	70.0	160.0	33,506.5	752.1	1,374.0	2,237.8	2,693.0
7	South Gippsland	2,527.0	336.0	6.0	26.0	25.0	8.0	488.2	149.2	30.6	131.1	713.8
8	Eastern Victoria	1,901.0	118.0	47.0	46.0	5.0	1.0	1,026.5	-	96.1	5,072.1	1,033.9
	Total	50,868.0	8,601.0	8,843.0	7,292.0	2,277.0	2,209.0	45,179.8	6,124.3	5,101.9	144,562.8	31,401.0

Table 6: Present (Discounted) Values of SLR/S Damages in the 21 Century, 5% Discount Rate with Growth in Asset Values (*$ million)*(See Table 2 for LUC Definitions).

	Region	Land Use Category										Sum
		LU1	LU2	LU3	LU4	LU5	LU6	LU7	LU8	LU9	LU10	
		Residental Area	Commercial Area	Industrial Area	Quarry Area	Farming Area	Utility	Social	Parks	Reserves	Other	
							2040					
1	Western Victoria	1,866.9	10.5	239.0	-	2,569.7	622.0	0.7	1,096.5	3,814.8	150.4	10,370.6
2	Geelong	1,156.1	160.3	1,363.8	673.6	2,660.5	3,863.0	150.9	131.2	2,592.4	594.6	13,346.3
3	West of Melbourne	101.5	70.4	4,601.1	-	62.6	1,913.7	556.9	53.7	21,210.0	205.0	28,774.9
4	Melbourne	134.5	7,511.0	332.8	-	-	860.6	253.8	13.5	512.3	4,496.4	14,114.9
5	Port Phillip	8,733.2	177.0	168.7	-	-	25.8	8.7	1.0	40.8	60.8	9,215.9
6	East of Melbourne	12,356.9	74.2	395.1	-	3,367.0	1,194.4	408.2	182.9	1,059.4	210.7	19,248.8
7	South Gippsland	1,885.7	56.4	44.2	-	3,325.8	226.7	16.9	2.2	11,630.3	294.6	17,482.8
8	Eastern Victoria	1,744.2	118.4	2.5	-	1,224.4	110.1	55.7	58.2	6,853.5	54.8	10,221.9
	Total	27,979.0	8,178.3	7,147.0	673.6	13,210.0	8,816.2	1,451.9	1,539.3	47,713.4	6,067.4	122.776.1
							2070					
1	Western Victoria	2,975.9	87.3	144.9	-	3,811.2	586.9	32.9	1,099.1	6,269.6	196.2	15,204.1
2	Geelong	3,580.0	235.7	1,489.8	820.5	3,043.7	4,112.6	222.5	86.3	4,227.5	301.7	18,120.3
3	West of Melbourne	919.0	127.5	4,787.2	-	178.5	2,796.2	706.4	76.1	45,400.8	258.6	55,250.1
4	Melbourne	818.3	30,730.5	420.1	-	-	977.1	805.5	15.2	695.5	6,296.7	40,758.9
5	Port Phillip	36,980.8	357.9	147.2	-	-	26.7	91.3	2.1	36.1	160.6	37,802.8
6	East of Melbourne	22,656.7	207.0	533.5	-	4,383.6	1,338.0	604.0	189.4	1,324.2	591.9	31,828.1
7	South Gippsland	2,081.4	67.9	156.4	-	3,815.5	211.1	18.4	2.2	18,701.3	299.8	25,353.9
8	Eastern Victoria	2,916.9	95.6	9.7	-	1,757.3	733.0	86.6	41.7	7,275.5	170.6	13,086.8
	Total	72,929.1	31,909.2	7,688.9	820.5	16,989.7	10,781.6	2,567.5	1,512.0	83,930.5	8,275.9	237,404.9
							2100					
1	Western Victoria	5,490.2	157.7	241.8	-	5,274.3	798.0	91.9	1,123.4	10,208.0	215.8	23,601.0
2	Geelong	5,353.3	444.8	1,604.2	1,032.1	3,295.9	6,179.4	454.2	143.7	6,795.6	342.3	25,645.5
3	West of Melbourne	2,310.3	164.9	5,288.4	-	193.1	4,000.0	1,166.7	135.0	71,475.9	746.9	85,481.4
4	Melbourne	830.3	46,678.3	4,237.4	-	-	1,407.2	1,241.9	18.9	1,298.6	6,814.1	62,526.7
5	Port Phillip	36,815.0	1,024.7	301.2	-	-	58.7	234.9	4.0	58.5	459.9	38,956.9
6	East of Melbourne	31,489.5	408.3	943.5	-	4,816.3	1,940.0	689.2	271.9	2,119.0	469.2	43,146.8
7	South Gippsland	3,464.5	105.0	215.4	-	4,353.7	279.2	37.2	3.7	29,584.6	351.9	38,395.3
8	Eastern Victoria	9,106.5	101.7	9.2	-	1,300.7	733.2	93.1	53.4	8,540.9	127.3	20,066.2
	Total	94,859.6	49,085.5	12,841.1	1,032.1	19,234.1	15,395.8	4,009.1	1,754.0	130,081.0	9,527.4	337,819.1

Table 7: The 40 **ABS SA2** Subregions with the Highest Present (Discounted) Values of SLR/S Damages in 2040, 5% Discount Rate with Growth in Asset Values (*$ million)*, No Adaptation Measures (See Table 2 for LUC Definitions, e.g., LU1 has five Classifications (LU11-LU15)). Note that some subregional aggregations vary slightly from those in Table 1.

	Region	**Land Use Category**										Sum
		LU1	LU2	LU3	LU4	LU5	LU6	LU7	LU8	LU9	LU10	
		Residential Area	Commercial Area	Industrial Area	Quarry Area	Farming Area	Utility	Social	Parks	Reserves	Other	
1	Werribee - Point Cook, Zone 3	-	-	93.4	-	62.6	1,564.8	538.8	27.1	8,515.3	0.0	10,802.1
2	Southbank, Zone 4	73.3	5,483.4	88.5	-	-	284.6	74.7	0.1	175.5	3,803.0	9,983.1
3	Foster, Zone 7	1,232.1	29.3	44.2	-	3,014.6	-	-	0.3	5,554.5	86.5	9,961.5
4	Hastings - Somers, Zone 6	278.5	6.9	286.3	-	6.6	29.9	217.7	0.0	1,253.7	4024.6	6,104.3
5	Wilsons Promontory, Zone 7	-	-	-	-	-	-	-	-	5,491.7	-	5,491.7
6	Koo Wee Rup, Zone 6	2,126.0	1.6	-	-	2,531.8	68.8	17.4	-	180.0	88.8	5,014.4
7	Laverton, Zone 3	-	-	3,905.6	-	-	-	-	-	-	-	3,905.6
8	Glenelg (Vic.), Zone 1	769.3	1.4	-	-	331.7	-	-	1,084.1	1,662.0	18.3	3,866.8
9	Albert Park, Zone 5	3,585.0	15.3	-	-	-	-	-	-	3.8	4.0	3,608.0
10	Pearcedale - Tooradin, Zone 6	2,108.8	11.4	8.0	-	690.9	53.5	0.3	20.7	325.6	18.4	3,237.6
11	Lorne - Anglesea, Zone 2	3.5	-	96.1	-	18.2	2,231.4	-	4.3	821.0	-	3,174.5
12	Moyne - West, Zone 1	544.8	2.7	153.2	-	1,498.9	12.3	0.5	1.3	770.0	57.4	3,041.0
13	Port Melbourne, Zone 5	2,966.7	15.1	0.1	-	-	-	0.9	1.0	5.5	46.0	3,035.3
14	Orbost, Zone 8	92.1	1.1	-	-	270.2	14.8	8.5	-	2,398.1	12.8	2,797.5
15	Yarram, Zone 8	428.1	1.3	0.5	-	554.0	-	19.2	50.8	1,502.6	11.1	2,567.7
16	Ocean Grove, Zone 2	458.6	75.6	-	-	1,218.8	332.5	-	66.8	179.2	156.1	2,487.5
17	Lara, Zone 2	104.3	-	233.5	-	307.1	1,262.9	-	10.1	341.5	166.3	2,425.8
18	Longford-Loch Sport, Zone 8	402.4	41.9	-	-	315.5	-	25.7	1.1	1,322.1	8.2	2,117.0
19	Docklands, Zone 4	49.8	967.1	-	-	-	292.1	42.4	5.7	97.7	580.3	2,035.0
20	Elwood, Zone 5	1,667.9	1.9	-	-	-	3.4	2.0	-	11.8	1.9	1,689.0
21	Wonthaggi-Inverloch, Zone 7	482.7	19.8	-	-	296.8	7.1	15.8	-	574.5	83.6	1,480.3
22	Newcomb - Moolap, Zone 2	87.3	0.7	530.5	110.8	159.0	8.9	-	14.0	85.5	3.1	1,332.5
23	Point Nepean, Zone 6	18.2	28.5	-	-	-	1,023.5	21.4	0.5	8.2	0.1	1,100.4
24	Corangamite - South, Zone 1	86.5	-	-	-	282.4	594.3	0.1	-	127.0	3.8	1,094.1
25	Bairnsdale, Zone 8	107.1	-	1.2	-	18.0	-	-	0.6	926.6	3.7	1,057.0
26	Seaford (Vic.), Zone 6	782.7	4.6	5.7	-	-	7.7	31.1	55.4	37.0	43.5	967.7
27	Point Lonsdale , Zone 2	296.9	6.6	15.4	-	248.6	11.1	-	1.0	156.7	180.0	916.2
28	Paynesville, Zone 8	436.1	8.0	0.5	-	42.3	-	1.2	5.7	351.0	12.0	856.7
29	Frankston, Zone 6	819.8	7.6	-	-	-	-	2.3	0.1	9.7	0.4	839.9
30	Moyne - East, Zone 1	10.0	-	-	-	23.5	-	-	-	781.4	0.2	815.2
31	Portarlington, Zone 2	68.8	-	-	45.3	266.9	1.4	-	2.8	195.3	3.5	719.8
32	Grovedale, Zone 2	11.2	-	-	-	21.0	2.2	-	-	624.9	2.8	662.1
33	Otway, Zone 1	49.2	0.2	-	-	255.3	15.3	0.1	0.1	288.5	19.1	627.8
34	Point Cook- East, Zone 3	32.9	-	-	-	-	-	-	0.1	541.5	25.9	600.4
35	West Melbourne, Zone 4	-	11.7	222.1	-	-	191.3	55.5	-	11.9	82.2	574.7
36	St Kilda, Zone 5	510.2	-	-	-	-	-	3.7	-	2.8	1.0	517.8
37	Lakes Entrance, Zone 8	258.1	66.2	0.3	-	22.0	95.3	1.2	-	64.8	6.9	514.8
38	Flinders, Zone 6	285.3	7.7	-	-	13.3	-	11.3	95.1	100.4	-	513.1
39	Altona, Zone 3	63.9	-	-	-	-	248.0	3.9	20.4	45.2	123.0	504.4
40	Warrnambool - South, Zone 1	172.8	2.9	2.1	-	109.8	-	-	7.1	130.7	28.1	453.5
	Total	21,470.1	6,820.5	5,687.2	156.1	12,580.0	8,357.1	1,095.8	1,476.3	35,675.2	9,706.7	103,494

Table 8: The 40 **ABS SA2** Subregions with the Highest Present (Discounted) Values of SLR/S Damages in 2070, 5% Discount Rate, with Growth in Asset Values (*$ million)*, No Adaptation Measures (See Table 2 for LUC Definitions, e.g., LU1 has five Classifications (LU11-LU15)). Note that some subregional aggregations vary slightly from those in Table 1.

	Region	**Land Use Category**										Sum
		LU1	LU2	LU3	LU4	LU5	LU6	LU7	LU8	LU9	LU10	
		Residental Area	Commercial Area	Industrial Area	Quarry Area	Farming Area	Utility	Social	Parks	Reserves	Other	
1	Werribee - Point Cook, Zone 3	32.4	-	93.4	-	178.5	2,524.2	426.5	16.9	16,404.5	12.6	19,688.8
2	Docklands, Zone 4	58.6	17,435.9	-	-	-	186.1	91.0	6.6	201.5	1,636.8	19,616.5
3	Port Melbourne, Zone 5	18,072.4	91.1	0.6	-	-	0.1	13.8	1.2	4.9	85.1	18,269.2
4	Southbank, Zone 4	165.1	10,382.2	72.2	-	-	181.8	403.5	1.2	237.0	4,251.5	15,694.4
5	Foster, Zone 7	1,123.2	18.9	25.6	-	3,458.6	-	-	0.4	8,985.1	75.7	13,687.6
6	Hastings - Somers, Zone 6	338.8	12.8	327.2	-	58.0	141.4	286.9	0.2	2981.3	7058.4	11,234.8
7	Elwood, Zone 5	9,643.3	9.5	-	-	-	3.2	11.8	0.0	10.7	11.3	9,689.7
8	Wilsons Promontory, Zone 7	-	-	-	-	-	-	-	-	8,761.4	-	8,761.4
9	Koo Wee Rup, Zone 6	2,751.8	0.9	1.6	-	3,315.8	170.5	25.5	0.3	230.5	155.1	6,652.0
10	Glenelg (Vic.), Zone 1	905.4	4.1	-	-	362.6	-	-	1,084.8	2,691.9	22.9	5,071.7
11	St Kilda, Zone 5	3,914.4	16.4	-	-	-	0.5	9.2	-	3.3	7.9	3,951.7
12	Lorne - Anglesea, Zone 2	233.7	9.7	154.1	-	115.7	2,062.1	-	3.1	1,333.0	3.2	3,914.7
13	Laverton, Zone 3	-	-	3,905.6	-	-	-	-	-	-	-	3,905.6
14	Longford - Loch Sport, Zone 8	1,176.2	24.7	4.3	-	797.5	-	43.5	3.0	1,760.4	90.4	3,899.9
15	Moyne - West, Zone 1	594.4	5.9	85.6	-	1,752.3	15.6	22.7	1.2	1,295.4	51.1	3,824.1
16	Orbost, Zone 8	144.3	2.7	0.2	-	268.0	669.3	18.1	2.0	2,475.4	22.4	3,602.4
17	Albert Park, Zone 5	3,238.6	21.4	0.1	-	-	-	50.5	0.0	3.0	6.1	3,319.7
18	Ocean Grove, Zone 2	1,188.2	92.7	-	-	1,252.9	336.0	-	36.7	320.7	65.5	3,292.8
19	Lara, Zone 2	275.8	-	184.9	-	277.3	1,665.2	14.1	5.5	542.9	73.8	3,039.6
20	Pearcedale - Tooradin, Zone 6	1,624.3	9.8	7.7	-	678.5	49.7	5.6	19.4	395.9	27.9	2,818.8
21	South Melbourne, Zone 5	2,111.0	201.7	33.9	-	-	1.6	0.4	0.0	0.3	39.2	2,388.1
22	Yarram, Zone 8	323.0	2.3	0.4	-	538.8	-	11.7	32.5	1,440.0	17.7	2,366.4
23	Wonthaggi-Inverloch, Zone 7	633.7	31.8	129.5	-	314.1	86.1	17.5	-	935.9	103.4	2,252.0
24	Frankston, Zone 6	2,093.7	37.4	14.2	-	-	-	4.2	0.1	11.9	8.0	2,169.6
25	Seaford (Vic.), Zone 6	1,376.3	16.0	32.1	-	-	12.2	40.2	56.5	48.5	146.9	1,728.7
26	Otway, Zone 1	501.8	15.2	-	-	640.9	15.7	0.8	0.2	496.3	18.2	1,689.1
27	Newcomb-Moolap, Zone 2	305.6	7.2	530.0	295.6	146.2	8.9	-	7.6	150.4	1.5	1,600.8
28	Warrnambool-South, Zone 1	574.3	9.7	4.2	-	598.5	-	-	6.5	212.9	77.2	1,483.3
29	Flinders, Zone 6	1,071.5	6.1	-	-	79.6	-	15.1	87.1	121.1	9.0	1,389.6
30	Grovedale, Zone 2	121.7	-	-	-	246.0	2.2	-	-	992.4	1.5	1,363.7
31	Moyne-East, Zone 1	44.0	2.1	-	-	18.8	0.1	3.0	-	1,257.3	0.3	1,325.6
32	Point Cook-East, Zone 3	99.9	-	-	-	-	-	-	23.8	1,158.7	26.4	1,308.8
33	Corangamite-South, Zone 1	70.6	48.5	-	-	375.5	555.4	5.5	-	210.3	5.1	1,270.9
34	Point Nepean, Zone 6	224.8	28.9	-	-	-	946.8	45.5	3.9	10.0	7.0	1,266.8
35	Portarlington, Zone 2	373.8	17.4	-	120.8	269.8	1.7	-	1.7	311.9	3.2	1,160.6
36	Point Lonsdale, Zone 2	597.7	5.7	12.2	-	201.0	10.4	-	0.5	254.8	73.0	1,155.4
37	Bairnsdale, Zone 8	168.6	5.1	2.0	-	51.9	-	-	0.4	901.4	9.5	1,138.9
38	Melbourne, Zone 4	0.5	767.1	-	-	-	-	42.9	-	11.8	173.1	995.4
39	Paynesville, Zone 8	546.0	7.6	0.4	-	33.8	-	0.7	3.1	349.6	17.7	959.0
40	West Melbourne, Zone 4	-	7.0	251.7	-	-	553.3	34.7	-	17.6	82.4	946.7
	Total	56,749.5	29,355.6	5,873.6	416.3	16,030.4	10,200.3	1,644.8	1,406.4	57,531.9	14,478.0	193,895

Table 9: The 40 **ABS SA2** Subregions with the Highest Present (Discounted) Values of SLR/S Damages in 2100, 5% Discount Rate, with Growth in Asset Values (*$ million)*, No Adaptation Measures (See Table 2 for LUC Definitions, e.g., LU1 has five Classifications (LU11-LU15)). Note that some subregional aggregations vary slightly from those in Table 1.

	Region	**Land Use Category**										Sum
		LU1	LU2	LU3	LU4	LU5	LU6	LU7	LU8	LU9	LU10	
		Residential Area	Commercial Area	Industrial Area	Quarry Area	Farming Area	Utility	Social	Parks	Reserves	Other	
1	Werribee - Point Cook, Zone 3	91.3	0.2	93.4	0.0	193.1	3,578.4	575.4	22.9	26,710.1	13.6	31,478.4
2	Docklands, Zone 4	54.7	28,526.3	0.0	0.0	0.0	252.0	126.0	9.2	328.1	1947.1	31,243.4
3	Foster, Zone 7	1721.8	26.0	36.6	0.0	3,916.0	0.0	0.0	1.2	14251.5	84.2	20,037.2
4	Southbank, Zone 4	84.3	13,840.6	67.7	0.0	0.0	247.3	665.4	1.1	496.7	4352.1	19,755.2
5	Hastings - Somers, Zone 6	537.4	21.6	514.3	0.0	55.1	213.8	291.0	2.1	4,062.0	9,553.9	15,251.6
6	Port Melbourne, Zone 5	13,724.8	247.6	1.1	0.0	0.0	0.2	26.7	2.8	8.1	103.0	14,114.4
7	Wilsons Promontory, Zone 7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13,820.3	0.0	13,820.3
8	Koo Wee Rup, Zone 6	4,808.5	1.2	1.7	0.0	3,572.7	304.9	45.2	1.0	373.6	156.2	9,264.8
9	St Kilda, Zone 5	8,449.9	133.7	1.3	0.0	0.0	3.7	14.9	0.0	5.2	36.4	8,645.1
10	Elwood, Zone 5	8,398.4	22.6	0.1	0.0	0.0	4.3	17.3	0.0	16.9	20.2	8,479.7
11	Glenelg (Vic.), Zone 1	1,687.9	7.8	0.0	0.0	497.1	0.0	0.0	1,085.2	4,302.4	27.2	7,607.7
12	Longford - Loch Sport, Zone 8	3,451.0	24.9	3.2	0.0	580.7	0.0	44.0	3.8	2,077.1	64.7	6,249.2
13	Lorne-Anglesea, Zone 2	620.3	66.1	162.8	0.0	177.5	2,810.2	0.0	4.6	2,191.6	10.2	6,043.3
14	Moyne - West, Zone 1	1,033.2	13.1	139.0	0.0	2,311.1	21.1	42.9	1.8	2,055.4	50.2	5,667.8
15	Lara, Zone 2	439.0	0.0	183.4	0.0	320.5	2,781.8	20.8	12.3	858.4	74.2	4,690.5
16	Orbost, Zone 8	688.7	4.7	0.6	0.0	198.3	670.0	23.3	2.7	2,914.1	19.1	4,521.5
17	Pearcedale - Tooradin, Zone 6	2,528.6	12.0	7.3	0.0	707.2	67.5	7.6	26.4	626.1	28.0	4,010.7
18	Ocean Grove, Zone 2	1,472.1	123.5	0.0	0.0	1,248.0	473.3	0.0	53.4	508.9	88.7	3,968.0
19	Laverton, Zone 3	0.0	0.0	3,905.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3,905.6
20	Albert Park, Zone 5	3,431.8	175.2	0.2	0.0	0.0	0.3	151.1	0.0	5.7	9.2	3,773.6
21	Wonthaggi-Inverloch, Zone 7	1,096.0	48.9	175.9	0.0	384.8	113.2	31.7	0.1	1,479.1	137.0	3,466.6
22	South Melbourne, Zone 5	2,809.0	405.9	51.1	0.0	0.0	2.2	2.0	0.0	0.5	144.7	3,415.4
23	Yarram, Zone 8	902.9	2.1	0.3	0.0	406.9	0.0	11.8	41.0	1,676.6	12.7	3,054.3
24	Otway, Zone 1	965.1	33.3	0.2	0.0	824.4	21.5	6.5	1.0	957.7	23.6	2,833.3
25	Paynesville, Zone 8	1,957.9	7.5	0.3	0.0	26.8	0.0	0.8	4.2	411.5	14.0	2,423.0
26	Moyne-East, Zone 1	84.9	2.6	0.0	0.0	297.9	0.1	4.3	0.1	2,025.2	3.4	2,418.5
27	Point Cook-East, Zone 3	402.9	0.7	0.0	0.0	0.0	0.0	0.0	40.6	1,824.0	36.4	2,304.6
28	Melbourne, Zone 4	0.5	1,976.7	0.0	0.0	0.0	1.8	64.0	0.0	18.7	206.0	2,267.8
29	Flinders, Zone 6	1,690.7	8.7	0.0	0.0	100.9	16.9	14.4	118.9	193.8	5.1	2,149.5
30	Warrnambool-South, Zone 1	980.3	18.6	19.6	0.0	670.2	0.0	0.0	20.4	337.0	78.0	2,124.0
31	Point Nepean, Zone 6	644.1	67.5	2.8	0.0	7.2	1,284.5	43.7	5.7	15.8	17.7	2,089.0
32	Grovedale, Zone 2	167.8	0.0	0.0	0.0	240.3	5.5	0.0	0.0	1,568.9	1.9	1,984.3
33	Newcomb-Moolap, Zone 2	509.2	32.2	553.9	443.4	173.9	12.0	0.0	10.5	237.8	3.6	1,976.5
34	Lakes Entrance, Zone 8	1610.0	45.9	1.2	0.0	34.1	63.2	2.1	0.2	81.7	8.4	1,846.8
35	Corangamite - South, Zone 1	120.9	64.9	0.0	0.0	501.7	754.8	32.7	0.0	336.4	5.0	1,816.4
36	Portarlington, Zone 2	605.2	34.2	0.6	181.2	323.7	3.5	0.0	9.7	495.5	10.7	1,664.3
37	Altona, Zone 3	760.5	25.9	238.4	0.0	0.0	193.3	3.9	28.4	159.3	167.0	1,576.7
38	Seaford (Vic.), Zone 6	1,050.4	22.1	67.4	0.0	0.0	19.0	60.8	80.1	78.6	71.8	1,450.2
39	Point Lonsdale, Zone 2	698.5	11.3	11.6	0.0	190.0	14.1	0.0	0.8	402.9	69.6	1,398.9
40	Bairnsdale, Zone 8	138.6	12.0	1.9	0.0	36.1	0.0	0.0	0.7	1,049.3	7.2	1,245.9
	Total	70,419.2	46,068.3	6,243.2	624.5	17,996.3	13,934.4	2,330.0	1,593.0	89,163.0	17,662.0	265,404.8

Table 10: A Comparative Summary of *Cumulative* Economic Damages for SLR/S in Victoria with a 5% Discount Rate and Assumed Growth in GSP and Land/Asset Values for 2040, 2070 and 2100. (The average % loss is the ratio of the cumulative (or total) PV of SLR/S costs to cumulative GSP in Victoria)

Year	Total PV of SLR/S Costs *$billion*	Total GSP VIC *$billion*	Loss from SLR/S as % of GSP
2040	122.78	7,082.47	1.73
2070	237.40	11,524.27	2.06
2100	337.82	12,597.70	2.68

Table 11: *Estimated Damages from SLR/S (% of GSP) in 2040, 2070 and 2100 in Victoria as Average Per Year Losses (from 2020), with Average GSP for Current (Non-Discounted) Dollar Values and Assumed Growth in Land/Asset Values and GSP*

	SLR/S Costs (avg/yr) *$billion*	GSP VIC (avg/yr) *$billion*	Loss from SLR/S as % of GSP
2040	9.44	547.69	1.73
2070	14.77	718.06	2.06
2100	23.66	883.24	2.68

3.4. Understanding the Tables

3.4.1. An Example of SLR/S Damages to Residential Property and Land (LU1) in the Geelong Region in 2040

Some care needs to be taken when interpreting the tables since, given the vast amount of model output, only part of the results are reported. Keep in mind Table 2 and Tables 5 and 6 in particular. For example, it might seem reasonable to divide the dollar amounts in Table 6 by the number of properties in LU11–LU13 in Table 5 to obtain a per property value. But that would be a mistake. The LU1 classification in Table 6 also includes LU14 (residential land) and LU15 (vacant residential site) from Table 2.

For clarification, an example of average SLR/S damages for the Geelong Region (i.e., Geelong Residential Area LU1) is provided. The SLR/S costs for a residential area of a particular region (see Table 6) at time 2040 includes the loss or damages to properties, residential land, and vacant residential land. The loss of property is estimated from the number of properties (see Table 5) and the value of these properties, which is based on ABS (2020*d*) for the Household and Income Survey by Sub-Region Level 2. The loss of land is estimated from the quantity of land damaged (by residential and vacant sites) and the average land price for that area (see Table 3). Damages from SLR/S are then adjusted by .50 — the average economic loss from SLR/S is 50% (weighted across damages from sea level rise and storm surge, taken separately, as indicated) of the economic value of land and properties — and damages are then discounted by 5% per year while assuming an increase in land/asset values over time to match the increase in state GSP.

Unpacking these terms provides the average cost of a property and land in a specific residential area. In 2040, for example, the PV of SLR/S costs for the Geelong Region is \$1,156 million (see Table 6), including \$614.5 million for properties, \$24.2 million for residential land, and \$517.3 mill for vacant residential sites. The total quantity of damaged properties is 3,044 (see Table 5). In total, 11.5 hectares and 536.6 hectares for residential land and vacant residential sites (not indicated in the table) are impacted.

The average value of a property ($v(LU11-13)$) (\$/property), resident land per hectare $v(LU14)$ (\$/hectare), and vacant residential land sites per hectare $v(LU15)$ (\$/hectare) in Geelong's LU1 residential area are estimated as

$$v(LU11-13) = (614,535,707/3044)/(0.5) = \$403,769/property \tag{4}$$

$$v(LU14) = (24,200,000/11.5)/(0.5) = \$4,216,469/ha \tag{5}$$

$$v(LU15) = (517,300,000/536.6)/(0.5) = \$1,928,224/ha \tag{6}$$

or the average PV of a residential property, residential land and a vacant residential site in 2040 for Geelong is \$403,769/property, \$4,216,469/ha, and \$1,928,224/ha, respectively. It is straightforward to convert to current values. The average PV of a residential property (\$403,769/property) in equation (4), for example, is determined using a a 5% discount rate and assumed growth in asset values (roughly 2% per year). Without a discount rate and without asset growth, the value per property is, on average, \$729,251. Without a discount rate but assuming asset growth, the average value per property is \$1,083,630.

3.4.2. Heterogeneity in Physical and Economic Damages Across Regions and Subregions

Along with aggregate physical and economic damages from SLR/S, a striking feature that comes out of the tables is the substantial heterogeneity or variability in damages across regions, subregions and LUCs. Taking 2100 as the reference year throughout in what follows — although the variability also applies to 2040 and 2070 — there are several key points to make here.

First, both physical and dollar damages to reserves (and conservation areas) are considerable, more than three times the damage in hectares, for example, compared to residential, commercial and industrial LUCs combined (Table 5). PV dollar damages alone are more than \$131 billion in 2100 or approximately 40% of the total damages for that year. Damages across regions and subregions are especially variable, with considerable damages in the Geelong, South Gippsland and the West of Melbourne regions. Estimated PV damages to reserves are more than \$23 billion in the Werribee – Point Cook SA 2 subregions alone. Foster and Wilsons Promontory SA 2 subregions also have considerable losses (Table 9).

Second, in terms of economic damages to residential areas (LU1), including losses in residential land (defined with no buildings of value) and vacant residential sites, Port Phillip and East of Melbourne regions dominate. Losses here are over \$36 billion and \$31 billion, respectively. The bulk of commercial damages occur in Melbourne (Table 6), especially in Docklands and Southbank, at \$28 billion and \$13 billion, respectively (Table 9).

Finally, major damages to industrial areas occur in the West of Melbourne region, but also in Melbourne itself. Losses to agriculture and agricultural land occur across the state, save for the Melbourne and Port Phillip regions. The largest impact is in Western Victoria with over \$5.2 billion in damages, but major losses also occur in the East of Melbourne and South Gippsland regions (Table 6).

3.5. Case Study: SLR/S Impacts on Wetlands, Mangroves and the Coastal Ecosystem

Natural areas such as parks, reserves and wetlands have 'intrinsic' value that is distinct from market values (National Oceans Office, 2001), providing places for native wildlife and other environmental benefits including the opportunity to relax outdoors and enjoy nature (Queensland Government, 2020). According to Costanza et al. (1997),"the services of ecological systems and the natural capital stocks that produce them are critical to the functioning of the Earth's life-support system. They contribute to human welfare, both directly and indirectly, and therefore represent part of the total economic value of the planet."

Victoria's coast contributes to the state through port and trade activity as well as tourism and a wide host of environmental and ecosystem services. There are roughly 70 million recreational visits across the Victorian coastline each year (DELWP, 2020*a*), and Costanza et al. (1997) argues that the ecosystem services generated by natural areas such as these are not fully 'captured' in commercial markets or adequately evaluated as environmental economic assets, and thus often are given too little weight in policy decisions.

Since the early 1990s, research on the economic valuation of natural resources, ecosystem services, and biodiversity has grown rapidly, with techniques that employ a number of different valuation approaches (van der Ploeg et al., 2010). A study by Blackwell (2006) provides some preliminary findings from the 'Economic Value of Australia's Natural Coastal Assets' report and studies by the National Oceans Office (2001), van der Ploeg et al. (2010) and Stoeckl et al. (2020) further analyse the value of ecosystem services.

The value of the contributions made by the ecosystem can be measured in dollars by applying the concept of total economic value (TEV), including constructing measures of non-market values either through the contingent valuation method, the travel cost method, benefit transfer or choice modelling approaches. The Common International Classification of Ecosystem Services (CICES)(Young and Potschin, 2018) has been developed to take into account these services in a systematic manner, avoiding the double counting of ecosystem values. CICES includes all of the broad categories of direct-use, indirect-use, option values, and non-use values identified in TEV.

In this case study, damages from SLR/S are estimated for the ecosystem services provided by wetlands and mangroves near the Victorian coastline, relying mostly on known estimates of per hectare values of ecosystem services, using techniques as indicated in van der Ploeg et al. (2010), and spatial layers for wetlands in Victoria provided by DELWP (2020*b*).

3.5.1. Total Economic Value (TEV) and the Meta-Analysis Approach

Following the narrative in Stoeckl et al. (2020), the TEV framework categorises benefits according to how people benefit (i.e., derive utility) from environmental goods and services: directly, indirectly, or through non-use. The *direct use value* is most frequently assessed using money as a metric, where individuals benefit from a good or service by paying for it. These goods and services are readily valued since their value is related to usage, which is usually directly observable. *Indirect use values* are those that generate utility indirectly, for example, beautiful landscapes, an ocean view, or heritage properties with historical and cultural value. These are harder to estimate because it not only requires one to estimate income compensation, an implicit measure of 'willingness to pay' for the service, but also a link between the environmental good or service and the human benefit or utility need to be quantified. *Non-use values* normally stem from existence values (e.g., knowing this aspect of the environment is simply there, even if not accessed or used) or bequest values (e.g., leaving the environment intact for future generations).

The meta-analysis, used here, is the quantitative analysis of statistical summary indicators for TEV reported in a series of similar empirical studies (van der Ploeg et al., 2010), basically synthesising the results of multiple studies that examine the same phenomenon through the identification of a common effect, which is then 'explained' using regression techniques in a meta-regression model (Stanley, 2001). Meta-analysis was first proposed as a research synthesis method by Glass (1976) and has since been developed and applied extensively. In addition, as used in this report, meta-analysis identifies consensus results across studies as a means of 'benefit transfer' to areas not formally studied, at least for those areas that have comparable biophysical and socio-economic characteristics.

3.5.2. SLR/S Damages on Ecosystem Values for Wetlands and Mangroves using TEV

The SLR/S effect on ecosystem values depends on the area lost by sea level rise and storm surge and the TEV value by hectare/per year of the Victorian coastal system. Key values here are the value of water purification, flood control, maintaining biodiversity, carbon sequestration, the value of mangroves for wave attenuation, improved air and water quality, and measures that prevent soil erosion along with opportunities to access tourism and cultural services.

The TEV use-values on the ecosystem that are applied in this report are based on van der Ploeg et al. (2010), and the PV of damages from SLR/S on coastal ecosystems for wetlands (C_eco) in a region is given by

$$C(eco) = \sum_{j=1}^{N} \sum_{t=1}^{T} \frac{S\_eco(j,t) * [TEV\_eco(j,t)]}{(1+\delta)^t} \tag{7}$$

where, in a manner essentially equivalent to equation (3) above, t is an annual time-step, j represents sub-region, S_eco is the land used for reserves, parks, and other environmental assets in the coastal areas (i.e., specifically wetlands in this case study) that are impacted by SLR/S in hectares, and TEV_eco is the TEV damage costs to these coastal assets. The value δ is the discount rate. As before, the analysis assumes a linear incremental increase (i.e., the average annual increment) in damages to each endpoint over time, given a baseline, and properly discount those damages at each annual time-step. Discounted economic damages are thus obtained for each year to a given endpoint and then aggregated for 2040, 2070 and 2100.

3.5.3. SLR/S Damages to affected Wetland Areas

Key spatial layers for Victoria's wetlands are based on DELWP (2020*b*). According to DELWP (2020*b*), the data set contains "polygons showing the extent and types of wetlands in Victoria, which was created in 2013 and was derived from the 1994 database (the state's first wetland geospatial inventory) and several local and regional wetland datasets." A number of updates have occurred to the dataset in 2014, 2017 and 2021. The 2014 update incorporated "new regional mapping, some supplementary mapping and repositioning of planimetrically inaccurate wetlands. Supplementary mapping involved identifying and delineating wetlands which had not previously been mapped, but did not modify the extent of existing wetlands. It was undertaken primarily using aerial photograph interpretation (photos from 2007 to 2011) supplemented with existing geospatial datasets that provided context and informed the identification of wetland boundaries (e.g., vegetation mapping, topography). Wetlands were classified (according to the new classification framework) into primary categories based on wetland system type, salinity regime, water regime, water source, dominant vegetation and wetland origin." The 2017 update "improved the accuracy of the layer by updating wetland mapping and attributes in the Melbourne area and for alpine bogs and fens in East and West Gippsland catchment regions. It also involved correcting inaccurate classification attributes and correcting wetland polygons for individual wetlands based on new data and feedback from wetland inventory users." The 2021 update incorporates "new mapping and refinements to existing wetland polygons for several regional wetland datasets. These include Tootgarook Swamp, Alpine Bogs, Mitchell River Floodplain Wetlands, Melbourne Water Billabongs and Mallee CMA Wetlands. The dataset currently consists of 38,799 polygons totalling 784,120 ha" (DELWP, 2020*b*).

Using both the wetland spatial layers (DELWP, 2020*b*) and the spatial layers for SLR/S (Department of Environment, Water, Land and Planning, 2020), the wetland area affected by SLR/S is obtained. Example spatial maps for wetland inundation are presented in Figure 3. Note that Figure 3 is distinct from Figures 1 and 2 — although there is some unavoidable overlap, they come from two initially different spatial data sets. From the spatial layers used here (DELWP, 2020*b*), wetlands are evidently defined to include freshwater and saline lakes, along with swamps and shallow waters in estuaries, bays and inlets subject to inundation. Table 12 reports the wetland areas affected by SLR/S in 2100 for a total of 288,335 impacted hectares, or about 36% of total wetland areas in the state.[5]

Like comparable TEV studies, the work by DELWP (2016), for example, classifies ecosys-

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[5] It is important to note that coastal wetland areas in other studies can vary depending on context and focus. In many cases, more traditional and limited definitions of wetlands are used. For example, based on the extent of coastal marsh 'Ecological Vegetation Classes' (EVCs) across Victoria by Boon et al. (2014), the wetland salt marsh areas, which are defined by certain specific criteria, are located in 30 coastal areas with a total area of 28,263 hectares. A study by DELWP (2016) builds on previous environmental and economic accounting to demonstrate the value of the ecosystem in Port Phillip Bay. The approach allows for the integration of terrestrial accounting with marine and coastal accounting to provide a more complete picture of both the economic and environmental attributes. In total, broadly defined ecosystem habitat for Port Phillip Bay alone is estimated at 196,315 hectares.

tem services related to, in this case, Port Phillip Bay, by provisioning services, regulating services, and cultural services. The ecosystem benefits accruing from Port Phillip Bay were estimated to be roughly AUD$30,000 per hectare in 2016 dollars (or $32,730 per ha at current prices using the Consumer Price Index (CPI) of Australia in 2016).

However, according to van der Ploeg et al. (2010), the TEV value of ecosystem services is more substantial at $USD47,542 per hectare (Table III.4, pp 20), using a classification for wetlands that includes: (i) provisioning services, (ii) regulating services, (iii) habitat services, and (iv) cultural services. The provisioning services ($USD1,982/ha) include the services of food, water, raw materials, medicinal resources, and ornamental resources. The regulating services ($USD38,537/ha) include a dominant part of water treatment/water purification ($USD33,966/ha), climate regulation, and moderation of extreme events and erosion prevention. Habitat services include the services of lifecycle maintenance and the maintenance of genetic diversify. Cultural services are the opportunity for recreation and tourism ($USD684/ha). The TEV value of ecosystem services at $USD47,542 per hectare in van der Ploeg et al. (2010) (Table III.4, pp 20) is equivalent to $74,576 per hectare at current AUD dollars (using the CPI of Australia and the current exchange rate).

In this report, a range of values for TEV is applied for Victoria's wetlands, including the higher TEV value from van der Ploeg et al. (2010) (Table III.4, pp 20) and the lower value from DELWP (2016). Similar to our work on 'dry land' above and to form ready comparisons, the discount rate is taken as 5%, growth in real asset values is assumed, and damages from inundation lose 50% of the value of the land area. (Although we have no precision on the possible extent of damages from inundation, arguably the discount rate should be lower in this case since these are primary environmental assets. It also follows that inundation impacts are likely more severe given that adaptation measures may be more limited for wetlands.) The PV of the SLR/S damages on Victoria wetlands is estimated following Equation (7).

Table 12 presents the PV losses for wetlands from SLR/S for both the low TEV and the high TEV case. Total losses attributable to wetlands can thus range from $46.0 to $104.9 billion in 2100. Details of this cost by zone are also presented in Table 12. Although there is some unavoidable but limited overlap in the spatial layers, it is important to note that these values are generally not double-counting the 'dry-land' damages to reserves and conservation areas in Section 3.3 above.

Table 12: Discounted Damages to Wetlands from SLR/S Effects in Victoria to 2100

	Zone	Affected Area in 2100 (*ha*)	Low Case of Cumulative Cost (*$Mill*)			High Case of Cumulative Cost (*$Mill*)		
			2040	2070	2100	2040	2070	2100
1	Western Victoria	92,231.1	2,723.8	9,534.9	14,730.6	5,724.1	21,725.4	33,563.9
2	Geelong	18,316.7	540.9	1,893.6	2,925.4	1,136.8	4,314.6	6,665.6
3	West of Melbourne	1,177.8	34.8	121.8	188.1	73.1	277.4	428.6
4	Melbourne	701.6	20.7	72.5	112.1	43.5	165.3	255.3
5	Port Phillip	9,166.0	270.7	947.6	1,463.9	568.9	2,159.1	3,335.6
6	East of Melbourne	2,756.3	81.4	285.0	440.2	171.1	649.3	1,003.1

Continued on next page

Table 12 – *Continued from previous page*

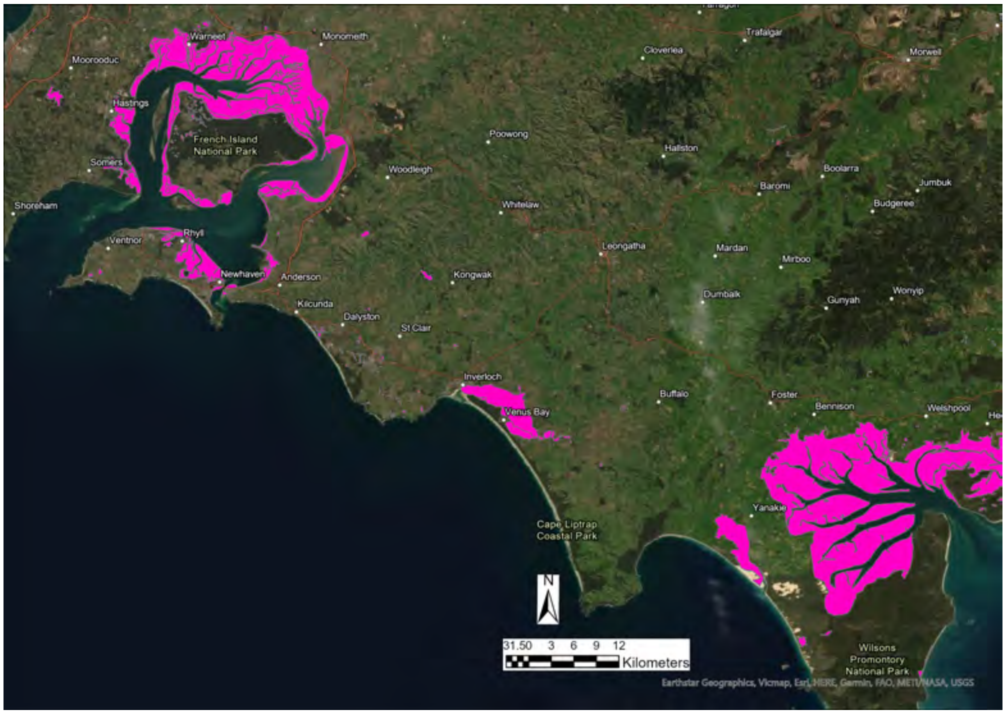
	Zone	Affected Area in 2100 (*ha*)	Low Case of Cumulative Cost (*$Mill*)			High Case of Cumulative Cost (*$Mill*)		
			2040	2070	2100	2040	2070	2100
7	South Gippsland	59,141.4	1,746.6	6,114.1	9,445.7	3,670.5	13,931.0	21,522.2
8	Eastern Victoria	104,844.3	3,096.2	10,838.9	16,745.1	6,506.9	24,696.5	38,154.0
	Total	288,335.3	8,515.1	29,808.3	46,051.3	17,894.8	67,918.5	104,928.4

Finally, a value for damages to mangroves is provided. Mangroves here are categorised as natural capital, important for the mediation of waste, toxins, and other nuisances, and as well as for the mediation of water flows. For mediation of waste, toxins, and other nuisances, mangroves help filter sediments from waterways and remove nutrients that can cause damage elsewhere. For mediation of flows, mangroves provide storm surge protection for communities and physical infrastructure through wave attenuation. Overall these values are difficult to estimate because of numerous interacting variables including,"the shape of near-shore, the presence of coral reefs offshore, the size of communities, value of infrastructure within, distance inland and elevation above sea level of potentially impacted areas." (Crossman et al., 2018).

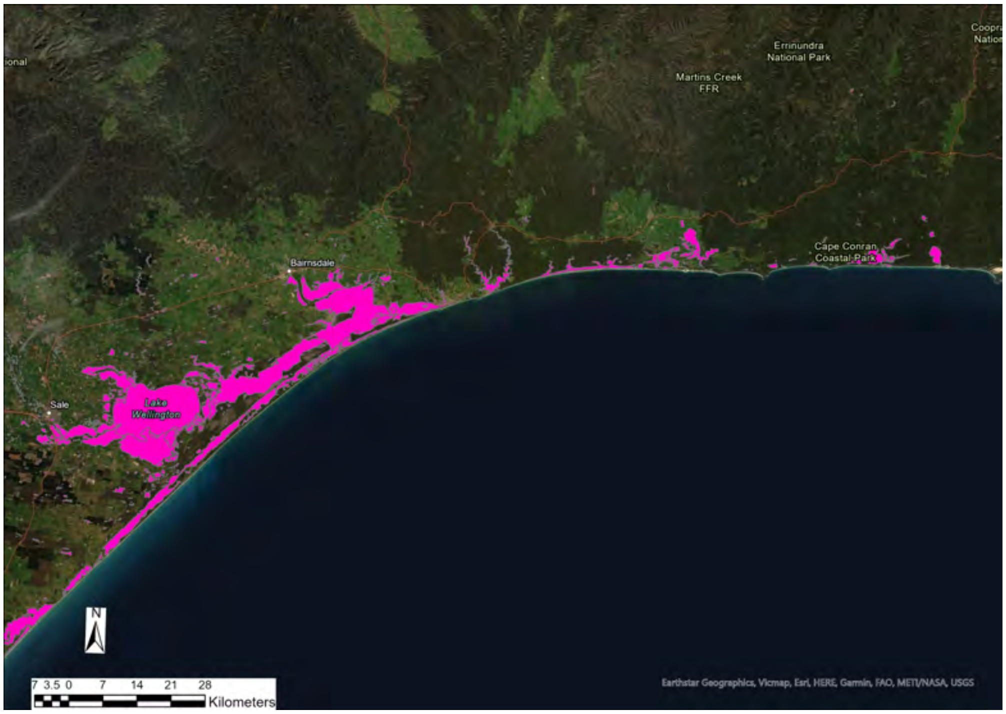
In this report estimates by Stoeckl et al. (2020) are used, where the values of mangroves include water purification, erosion and flood control; gene-pool/habitat/nursery value maintenance, and carbon sequestration. When considering other regulatory values, Stoeckl et al. (2020) grouped MVG 23 (mangroves) and MVG 24 (inland aquatic) together as 'wetlands' since per-hectare value estimates were similar, and pooling helped reduce transfer error. However, when focusing on gene-pool/habitat values, it is sensible to distinguish between freshwater and marine environments. In addition, there are numerous studies of both wetlands and mangroves, so it is possible to retain the benefits of 'pooling' without combining MVG 23 and MVG 24. There are also a handful of studies that provided estimates of gene-pool values in estuaries (MVG 28), and so Stoeckl et al. (2020) also considers them separately. With this in mind, the average value of mangroves used in this report, across all categories, is estimated to be $3,172.30 per hectare per year (Stoeckl et al., 2020). Applied to an area of 5,177 hectares (Boon et al., 2014), and using a 5% discount rate and assumed growth in asset values, gives SLR/S damages to mangroves increasing from $14.8 million in 2040 to $51.9 million in 2070 and $80.1 million in 2100.

Figure 3: Example Wetland Loss in the SLR/S Potentially Affected Areas, 2100

(a) Zone 7: South Gippsland



(b) Zone 8: Eastern Victoria



Source: Department of Environment, Water, Land and Planning (2020). (Note change in scale.)

3.6. Adaptation Case Study: Natural Barriers

There is a growing interest in using natural habitats, such as mangroves, to defend coastlines. Here, we summarise work done on the protective services of mangroves and rock revetments as adaption measures against SLR and storm surge for Victoria (see, Strain et al. (2022)). The five areas are specific or designated locations (given by precise coordinates) within Barwon Heads (Carr Street), Williamstown (Gloucester Park), Hastings (Foreshore Reserve), Phillip Island (Beach Crescent New Haven) and Stony Point (near Boat Ramp). All calculations were based on the assumption that both the mangroves and rock revetments will provide complete protection from SLR and storm surge, as determined by our measurements of wave attenuation.

Residential and commercial values and source material were drawn from the analysis above (see Section 4.3) and ecosystem service values were drawn from the material in Sections 4.5.1 to 4.5.3. For the five regions in this study, ecosystem service damages roughly range from 22–45% of market value damages on average.

Across the five locations, the total cost (economic and non-market) of SLR was $4.12 to $122.00 million per km2, by 2040 and $15.5 to $333.9 million per km2, by 2100 (see Table 13). The costs of replanting mangroves ranged between $3.35 and $39.5, per m2 (Table 13), and the costs of constructing rock revetments ranged between $200 and $5,000, per m2 (Table 13). The total avoided damage costs of the mangroves ranged between $0.001 and $70.70 million per m2 AUD, whereas the avoided damage costs of the rock revetments ranged between $0.001 and $8.21 million per m2 (Table 13). On average, the upfront cost of planting mangroves were significantly cheaper than constructing rock revetments, but the rock revetments required less land than mangroves to achieve the same wave attenuation benefits (Table 13). At all locations, the area occupied and therefore the total averted damages of the mangroves were greater than the rock revetments (Table 13).

Overall, the study by Strain et al. (2022) found that mangroves are cost effective alternatives to rock revetments for risk reduction and adaptation. In most locations, the natural mangrove forests delivered wave attenuation benefits that were comparable or greater than rock revetments. The upfront costs of planting mangroves are also significantly cheaper than building rock revetments. The coastal area and hence the damages averted by mangroves to coastal properties from SLR and storm surge, under current conditions was greater than the rock revetments. Moreover, vegetated habitats such as mangroves provide other ecosystems services of economic importance such as biodiversity, fisheries protection, and tourism, not considered in our work. However, replanting mangroves forests requires more coastal land than rock revetments and there is greater uncertainty about how many mangroves need to be planted and how long it will take to achieve the desired coastal protection benefits. This may suggest that planting mangroves may not be a viable solution for coastal protection in areas which are heavily populated or where immediate interventions are required. It does, however, indicate the need for a decision support framework that at least considers nature-based solutions in coastal planning and management.

Table 13: The costs of sea level rise (SLR) by 2040 or 2100, for each location and characteristics and replacement and total averted damages costs for the two habitats, at each location*

Location	Cost of SLR	**Mangroves**	**Rock revetments**						
	Economic & Non-market ($ million/ km^2)	Density of plants (m2)	Onshore length (m)	Width (m)	Averted damages costs (million/m2)	Crest height ADH (m)	Onshore length (m)	Cost of building, incl rocks (m2)**	Averted damages costs (million/ m2)
Barwon Heads	Economic: 11.98, 32.50 Non-market: 0.71, 10.04	Adults: 0.39 Saplings: 5.00 Seedlings: 0.00 Total: 5.39	271	28.99	0.01 – 0.33	1.772	40.6	$200	0.001–0.003
Williamstown	Economic: 22.76, 181.52 Non-market: 4.81, 37.56	Adults: 0.28 Saplings: 0.06 Seedlings: 0.00 Total: 0.34	468.7	21.95	6.23 – 49.47	2.553	381.91	$5,000	0.59 – 4.69
Hastings	Economic: 11.98, 326.94 Non-market 1.24, 12.95	Adults: 0.43 Saplings: 0.17 Seedlings: 3.60 Total: 4.20	3650	57	25.4 – 70.7	2.932	605.83	$5,000	0.22 – 0.61
Phillip Island	Economic: 3.36, 9.51 Non-market: 4.14, 6.04	Adults: 0.06 Saplings: 0.56 Seedlings: 0.00 Total: 0.62	450	87.95	0.17 – 0.62	2.045	112.23	$5,000	0.01 – 0.03
Stony Point	Economic: 120.98, 326.94 Non-market: 1.24, 12.95	Adults: 0.58 Saplings: 0.58 Seedlings: 0.90 Total: 2.06	1430	93.00	16.26 – 45.2	2.647	98.12	$2,000	2.95 – 8.21

**The costs of planting mangrove seeds (1-6: $3.35 – 20.1) or seedlings (1-6: $6.65 – 39.5) were obtained from https://seagrass.com.au. **Cost of building including rocks (m2) were obtained from www.delwp.vic.gov.au.*

It is important to note, finally, that mangroves (and rock revetments) may not provide complete protection form SLR/SS. A further investigation into the potential lack of success from mangrove planting or restoration and where mangroves should be planted or restored in the first place is warranted.

4. The Climate Risk Approach: Coastal Inundation Property Analysis

The modelling by Climate Risk aims to estimate a range of potential impacts across what mainstream science considers to be a plausible set of scenarios for future ocean and atmospheric behaviour. It uses analysis calculated by the probabilistic and computational 'Climate Risk Engines' (https://www.climaterisk.com.au/). The Climate Risk Engines overlay specific asset information with hazard data and climate change projections to analyse the impacts of climate change and extreme weather on the annual costs of damages and loss of financial value of any given property. The aim is to identify and quantify the probabilities of weather and climate-driven integrated coastal inundation risk for more than 3.8 million residential and commercial properties and critical infrastructure within the state of Victoria, Australia.

Supporting a collaborative project led by the University of Melbourne, this section of the report examines the costs of projected damages from sea level rise on coastal communities and coastal assets and the relative costs of investment in adaptation measures for selected case studies to mitigate that damage. We show the aggregated damage to properties and impacts to the economy into the future through various metrics. These include the 'Value at Risk', 'Technical Insurance Premiums' (damage cost to building), the number of properties in each risk rating category and the number of exposed properties at a state-wide and suburb level where the top 40 suburbs with the highest number of high-risk properties are ranked for the years 1990 (baseline), 2040, 2070 and 2100.

An additional analysis for a series of specific regional and metropolitan case study areas is also provided, capturing risk to properties and critical infrastructure, which may have ramifications for the operation of infrastructure servicing the community. The areas chosen were: the Bellarine Peninsula and townships along the coast toward Torquay, Wyndham (LGA), Phillip Island and the suburbs of Hastings and Williamstown. Proxy adaptation measures were also applied to the properties in these case study areas. These involved assets having minimum elevation above sea level of at least the nominated pathway height of 1, 2, 3 or 4 metres. Each of these heights hypothetically represents the extent of adaptation required to respond to the impacts from sea level rise. It is important to note that the height elevation is taken as a proxy for a variety of defence measures (e.g., natural and artificial barriers and retreat from the coast). The height elevation does not identify 'how' adaptation should be achieved to alter the economic outcomes. Instead, any identification of how adaptation might be achieved is noted as subject to site-specific planning and management decisions that address the applicable regulatory, infrastructure/ building, environmental, engineering, and other variable requirements. The analysis, in other words, is simply designed to highlight assets at risk and the extent of adaptation measures needed (by elevation) to mitigate that risk.

4.1. Risk Reporting Parameters

There are a variety of risk reporting metrics used throughout the analysis, which we summarise here. The Technical Insurance Premium (TIP) is defined for our purposes as the Annual Average Loss (AAL) per 'Representative Property' for all hazard impacts combined. The TIP is based on the cost of damage to a property, expressed in 'current dollars' with no discounting or adjustments for other potential transaction costs.

The Total TIP (TTIP) is the sum of all TIPs for all properties in any given area, for example, all locations in an LGA, or within a certain distance from the coast. As such, the TTIP is useful in drawing attention to the likely financial risk associated with climate change hazards. The TIP can be derived where a Value at Risk (VAR%) and total replacement cost of a property is given, or

$$TIP = VAR\% * Asset\,Replacement\,Cost \tag{8}$$

where VAR% is the percentage of the value of the property at risk.

Value-At-Risk (VAR%) and Maximum-to-Date VAR (MVAR): Rearranging equation (8), the Percentage of Value at Risk (VAR%) is the Technical Insurance Premium expressed as a percentage of a single property's replacement cost, specified for a one-year period with no discounting of the TIP or the property replacement cost, so that

$$VAR\% = TIP/Asset\,Replacement\,Cost \tag{9}$$

The VAR% can also be applied to a portfolio of assets, in which case Average VAR% is the TTIP divided by the total replacement value of all assets, making it a non-dimensional average for TIP. Unless otherwise stated, for each analysed year, the highest VAR(%) up to that date is used. This is because climate models can have considerable variability over time and some hazards may fall for some periods, which can lead to misleading data if only a single year is presented. Therefore, the Maximum-to-Date-VAR is used as default because it provides a single insight into the peak physically damaging stress placed on each asset from extreme weather and climate change observed in the modelling results up to that year.

Number of High-Risk Properties (HRP#): In this analysis, a representative property is classed as becoming 'High Risk' if its Maximum-to-Date-Value-At-Risk % for a given year exceeds 1.0%. This is based on the USA Federal Emergency Management Agency (FEMA) thresholds for government insurance schemes, which highlight properties in an (historic) 1-in-100 flood zone, also known as "Rating A Zones". The number of High-Risk properties is the sum of all properties for which the MVAR% is above 1.0% each year. The number of Moderate Risk Properties is the sum of all properties for which the MVAR% is between 0.2% and 1.0%.

High Risk Properties as a Percentage (HRP%): The number of High-Risk Properties can also be expressed as a percentage of all properties in each area. High Risk Properties are usually the result of substantial exposure to severely damaging hazards such as flooding or coastal inundation. This indicator is therefore useful to show where there are areas which have a concentration of acute risk.

4.2. Key Findings

Findings show the percentage of state-wide addresses exposed to coastal inundation risk increasing over time. The increase in risk is largely driven by a subset of properties with high-risk which are predicted to experience significant impacts from climate change and extreme weather. The High-Risk Property % results increase from 13,000 (HRP% of 0.34%) in 1990 to 152,000 (HRP% of 3.91%) in 2100.

The total cost of damage to properties (buildings only) for the State (shown through the Total Technical Insurance Premium) is expected to be $39 billion at the end of the century (assuming an average and limited replacement cost of $320,000 per property). Using a more broad level of damages to residential property market values, over and above replacement cost, the Climate Adjusted Value (CAV) provided by Climate Risk in the year 2040, 2070 and 2100 gives losses of $18.06 billion, $51.62 billion and $104.06 billion respectively (base case) with no assumed increase in asset values over time. If the total market value of the property portfolio is worth almost $2.9 trillion in Victoria, the CAV is projected to force a correction to the portfolio, losing 0.6% in 2040 1.8% in 2070 and 3.7% in 2100 in value for the state as a whole.

The suburb level analysis found the Total Technical Insurance Premium from Southbank, Docklands and Port Melbourne contribute to a large proportion of the state's TTIP in 2100, driven by coastal inundation. A case study area stress test found that critical infrastructure assets in some areas are also at risk to coastal inundation, which may result in further consequential costs to the economy due to inability to access critical services such as water, power and transport during extreme weather events.

Various hypothetical or proxy adaptation pathways (1 to 4 metre elevation increase) were tested and proven to significantly reduce the coastal inundation risk to assets. Overall, if left unadapted, both residential properties and critical infrastructure may fail more frequently and for longer periods of time as climate change impacts worsen and sea levels continue to rise. This will have substantial economic implications for Victoria's coastal regions and the State of Victoria in general.

4.3. Coastal Inundation and Asset Data

For this analysis, the Climate Risk Engines (https://www.climaterisk.com.au/) include an intermediate sea level projection from (Haigh et al., 2014), where the projection of sea level rise is seen to increase from: 0.00m in 1990, to 0.33m in 2040, 0.84m in 2070, and 1.52m in 2100. The Climate Risk Engines also include an adjustment to take into account the effects of land movement. The relative land heights due to the land moving vertically are computed using Glacial Isostatic Adjustment (GIA), as recommended by the Permanent Service for Mean Sea Level.

For this project the Climate Risk Engines compute risks to each property in terms of damage costs and degradation in asset value. Data is combined in a cloud cluster of parallelised high-speed servers that computes risk data for coastal inundation to the year 2100. The main vehicle by which climate change impacts are analysed is the changing probability of events capable of breaching the design threshold (e.g., flood level) of an asset or its component 'elements'. The probability of a hazard event (in this case coastal inundation) occurring is measured using an Annual Exceedance Probability (AEP) – a conventional industry standard way of assessing low probability, high consequence events.

The probability of a breach is calculated based on mathematical joint probability methods that combine the statistical distributions of astronomical tides, near-shore waves/storm surge, and tectonic movement with annual sea-level rise added incrementally. The results can be sensitivity tested using Monte Carlo resampling or by applying a range of sea level rise projections. While the effects of wave set-up (the general effect of elevated water height at the coast) are included, the impact of wave run-up (breaking waves running further up the beach than the mean water level, before slipping back) is not.

Most critical is the elevation of the civil element (e.g., floor heights), as empirical data shows a sharp increase in loss once water breaches floor levels, along with a property's elevation above sea-level. A property's elevation above sea level has been sourced from the Digital Elevation Model (DEM) 5 Metre Grid of Australia derived from LiDAR. This model represents a National (bare earth) DEM which has been derived from some 236 individual LiDAR surveys between 2001 and 2015 (AUS DEM, 2011).

4.4. Methodology

The Climate Risk Engines combine engineering with statistical analysis of historical weather and climate projections, along with probabilistic methods for financial analysis of risk and value from coastal inundation. The Climate Risk Engines risk processing methodology is shown below:

1. The methodology begins with a single point location being defined for each of the 3.88 million addresses within Victoria.
2. Baseline extreme event frequency is calculated from historical weather information.
3. Extreme event frequency is then adjusted under various climate change scenarios.
4. Hazard data for each location is passed to climate risk engines.
5. Extreme weather events are matched with relevant contextual information.
6. A default archetype that best represents Victorian properties is applied. Each archetype represents property's construction type and elements and materials are defined in terms of failure thresholds to coastal inundation.
7. Climate Risk Engines then calculates the failure probability for each element under each hazard every year until 2100 using statistical analysis.
8. Results are aggregated to a state and suburb level using the Australian Statistical Geography Standard (ASGS) digital boundaries — state suburb level ABS (2021).
9. Outputs are available in a variety of formats to support the desired project outcomes.

The key metrics used for the analysis were:

- Average Maximum-to-Date Value-at-Risk Percentage (MVAR%), including: MVAR% = TIP / Replacement Cost; A building is assumed to be 100% damaged/not operational when a 28% MVAR from coastal inundation is reached.

- Number of High, Moderate and Low-Risk Properties (#HRP, #MRP, #LRP): Climate Risk's Asset Risk Ratings are derived from US Federal Emergency Management Agency (FEMA) standards, which are used for pricing many insurance premiums in the USA. Rankings are based on TIP as a Percentage of Replacement Cost (MVAR). Climate Risk's (along with other organisations such as XDI and Climate Valuation) ratings for MVAR are:
    - High Risk = $MVAR\% > 1\%$: Insurance may be high cost or unavailable unless adaptation actions are undertaken.
    - Moderate Risk = $0.2\% < MVAR\% < 1\%$: Risk may lead to higher insurance cost.
    - Low Risk = $MVAR\% < 0.2\%$.
- Percentage of High-Risk Properties (HRP%): Number of properties with a MVAR% $> 1\%$/ total properties.
- Percentage increase in the Number of High-Risk Properties from 1990 to 2100.
- Number of properties exposed to each hazard. MVAR $> 0\%$.
- Average and Total Technical Insurance Premium (Average TIP, TTIP, \$): TTIP = MVAR * Replacement Cost (\$).
- Climate Adjusted Value (CAV, \$).

This analysis is based on the 'Simple House' archetype which includes design and construction materials with a floor elevation of zero meters, standard concrete foundations, no specialised forest fire protection. The baseline case of this analysis uses the status quo development position with no adaptation, which is the standard requirement to establish baseline risk projections — this is consistent with expectations of Australian Prudential Regulation Authority (APRA), Bank of England and other regulatory authorities. These design and construction settings materially impact the vulnerability of the 'Representative Property' to the hazards to which it is likely to be exposed. The replacement cost of each building is \$320,000 with a market value of \$740,000, based on averages for the Victorian property market in 2018-2019 (ABS, 2020*c*). Costs are fixed across all years analysed, keeping the focus on the impact of climate change, rather than abstract assumptions about changes in property values. State-wide average costs are used and are considered a reasonable standard approach with an unknown portfolio. All assumptions of variable pricing mean the regional comparisons become distorted by value. Coastal properties may be higher in value, but will decrease away from major cities, and be affected by the typical age of the suburb.

A series of case study areas were selected for a deep dive analysis to investigate the effects of four hypothetical adaptation options to minimise coastal inundation risk to properties. The case study areas are: The Bellarine Peninsula and townships along the coast toward Torquay, Wyndham (LGA), Phillip Island, and the suburbs of Hastings and Williamstown.

The hypothetical adaptation actions applied to our model were an artificial sea water defence of 1, 2, 3 and 4 metres compared to the baseline non-adapted analysis. As indicated, each of these heights hypothetically represents the extent of adaptation required to respond to the impacts from sea level rise. It is important to note that the height elevation is taken as a proxy for a variety of defence measures (e.g., natural and artificial barriers and retreat from the coast). The height elevation does not identify 'how' adaptation should be achieved to alter the economic outcomes.

In addition to the adaptation analysis undertaken for the case study sites, areas with critical infrastructure were also analysed to capture any dependency risk or outages of critical operations. The critical infrastructure assets included in this project were substations, telecommunication towers, emergency (police, fire and ambulance stations, hospitals) and education facilities (primary, secondary and tertiary). This was derived from DELWP (2021) and Australian Communications and Media Authority (ACMA, 2021).

4.5. Detailed Results for Victoria

The aggregated coastal inundation risk are obtained for all 3.88 million addresses in Victoria over time (with a 1990 baseline) for 2040, 2070 and 2100, without adaptation. Outputs include: (i) Percentage of exposed properties ($VAR > 0\%$); (ii) Count and percentage of assets within each risk category, Low Risk Property (LRP), Moderate Risk Property (MRP) and High-Risk Property (HRP); Average Value at Risk Percentage (VAR%); and Average and Total associated cost of damage through the Technical Insurance Premiums (TIP and TTIP, $). (see Figure 4 and Figure 5).

From our sample of 3.88 million properties in Victoria, the number of properties exposed to damage ($VAR\% > 0\%$) from coastal inundation will be 174,409 in 2040, 199,331 in 2070, and 333,470 (6% of total) in 2100, almost doubling from 2040. Figure 4 presents the 'greatest counts' in 2100 in Victoria and the Port Phillip and the Western Port Bay.

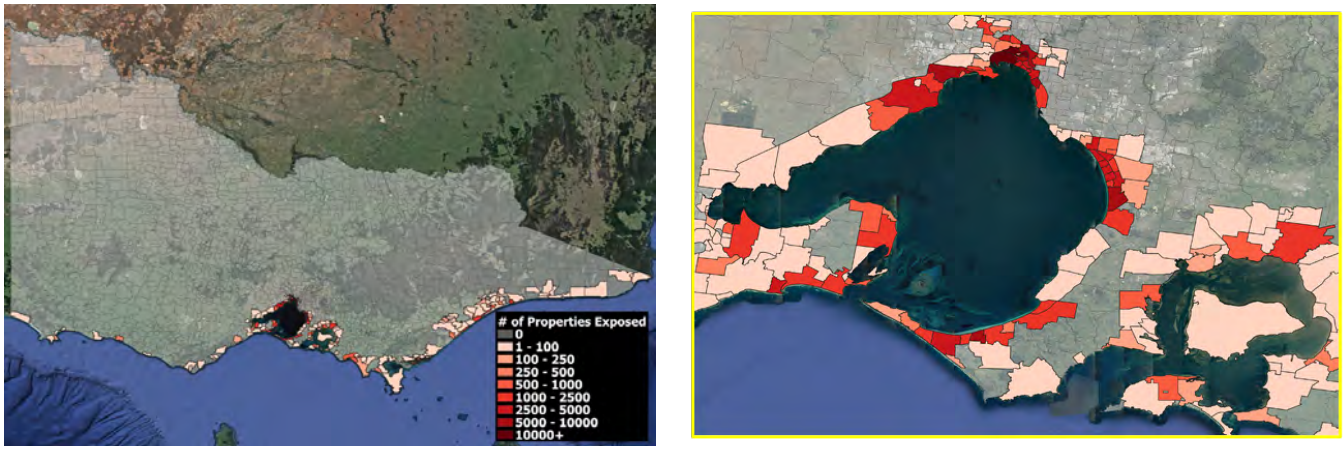
The number of assets within each risk category are shown below (percentage also shown):

- High Risk: 33,205 (0.86% of state total) properties in 2040, increasing to 87,019 in 2070 (2.2%) and further raising to 151,755 (3.9%) by 2100.
- Moderate Risk: 16,096 (0.41% of state total) properties in 2040, increasing to 17,451 (0.45%) in 2070 and decreasing to 13,144 (0.34%) by 2100.
- Low Risk: 3.83 million (98.7% of state total) properties in 2040, decreasing to 3.78 million (97.3%) in 2070 and further decreasing to 3.72 million (95.8%) by 2100.

The increase in risk for the state is driven by the high-risk subset of properties which will experience significant impacts from climate change and extreme weather, while many properties will have only small cost impacts.

The state's average per property Value-at-Risk (%) due to coastal inundation increases over time, from: 0.006% in 1990 (baseline), 0.20% in 2040, 1.24% in 2070, and 3.11% in 2100 (Figure 5(i)). The TTIP increases throughout the course of the century, with a notable increase in TTIP observed from 2030 onwards. This has the potential to lead to serviceability

Figure 4: The ‘Greatest Counts’ in 2100: Heatmaps showing the number of exposed properties (Value-at-Risk greater than 0%) from coastal inundation within suburbs across the state of Victoria in the year 2100.



i) Victoria

ii) Port Phillip and the Western Port Bay

pressures and defaults. The TTIP and Average TIP is estimated at: $75 million (Average TIP $19) in 1990, $2 billion (Average TIP: $638) in 2040, $15 billion (Average TIP: $3,969) in 2070, and $39 billion (Average TIP: $9,963) in 2100 (Figure 5.)

4.5.1. Climate Adjusted Value

The Climate Adjusted Value (CAV) — the adjusted market value for the representative property used to account for expected impacts of climate change — assumes that funding is finite and fixed, and that money spent on insurance or self-insurance against climate related hazards must redirect financial resources away from servicing the mortgage. Using a default interest rate, this diversion of funds is calculated as an equivalent reduction in the principal value of the loan that may be borrowed.

As the value of a property may fluctuate with the market, the reduction in the lending capacity is expressed as a percentage reduction in equivalent value. The CAV is therefore the percentage reduction in value for the ‘Representative Property’, relative to an equivalent property unaffected by extreme weather and climate change.

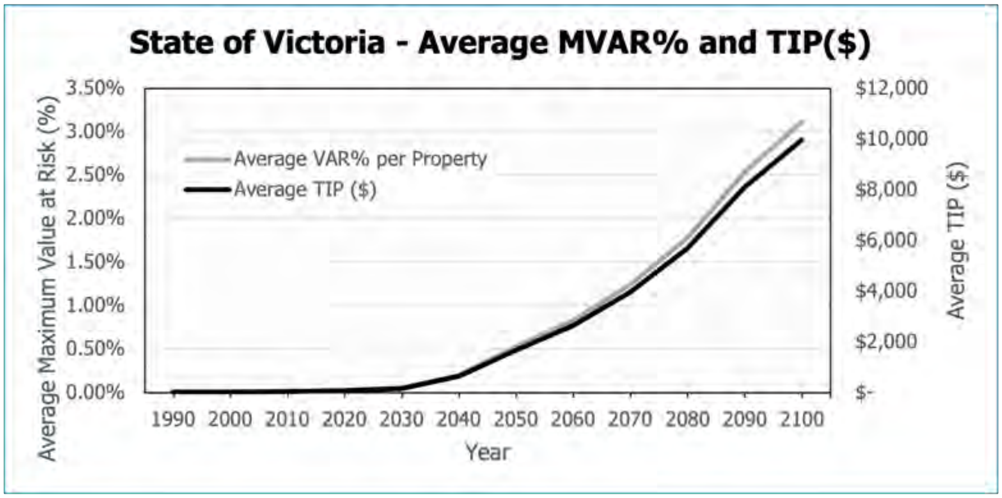
Assumptions: For this analysis, the replacement value at each address is assumed to be $320K in keeping with rebuild costs averages for Victorian dwellings with an average market value of $740K per property. The case of a 5% interest rate is taken as the base case.

The formula below is used to achieve a CAV for the total ‘Market Value’, the ‘Total Technical Insurance Premium’ (TTIP) and nominated interest rate.

$$CAV = (MarketValue * Interest\,Rate - TTIP)/Interest\,Rate \tag{10}$$

With this approach, the projected Total Technical Insurance Premium for the state is

Figure 5: State Analysis: Average VAR% and TIP$



Note to Figure 5: Average Maximum-to-Date Value-at-Risk Percentage (MVAR%, on left axis) and Average Technical Insurance Premium (TIP, $, on right axis) from Coastal Inundation over time for all addresses within the state of Victoria. © Copyright Climate Risk Pty Ltd, 2021.

used to calculate the CAV, noting that market values are not accumulating over time, SLR/S is an event in a given year that will do a certain amount of damage to infrastructure only in that year. CAV damages will clearly increase over time with global warming.

Results for CAV show a loss of $18.06 billion in 2040, $51.62 billion in 2070 and more than $104.06 in 2100. If the total market value of the property portfolio is worth almost $2.9 trillion in Victoria, the CAV is projected to force a correction to the portfolio, losing 0.6% in 2040 1.8% in 2070 and 3.7% in 2100 in value for the state as a whole.

4.6. Suburb Breakdown Analysis

This section reports the top 40 suburbs that have the highest number of High-Risk Properties (#HRP) across Victoria for years (1990 baseline), 2040, 2070 and 2100, assuming no adaptation (see Table 14 – Table 16). Also presented are the:

- Count of assets within each low, moderate, and high-risk category (#LRP, #MRP, #HRP),
- Average and total associated cost of damage through the Technical Insurance Premiums (TIP and TTIP, $),
- Count of exposed $MVAR\% > 0\%$ properties within suburbs,
- The percentage of high-risk properties (HRP%), and
- The percentage change in #HRP from 2040 to 2100.

The total number of suburbs with at least one property exposed to coastal inundation is 232 in 2040 (Table 14), 249 in 2070 (Table 15) and 269 in 2100 (Table 16). The suburbs of Southbank and Docklands have the greatest number of HRP across all years.

From all properties within Southbank in 2040, there are 16,646 properties (38% of suburb) classified as HRP and a TTIP of $692 mill (Table 14). In 2070, HRP increases to 31,672 (72% of suburb) and TTIP to $7 billion (Table 15), and at the end of the century there will be 37,589 HRPs (85% of suburb) and a TTIP of $11.7 billion in 2100, driven by coastal inundation (Table 16).

From all properties within Docklands in 2040, there are 3,270 properties (13% of suburb) classified as HRP and a TTIP of $136 mill. In 2070, HRP increases to 11,403 (45% of suburb) and TTIP to $1.7 billion, and at the end of the century there will be 21,140 (84% of suburb) and a TTIP of $5.5 billion, driven by coastal inundation.

Port Melbourne has the third highest HRP in 2100. In 2040 there are 444 properties (3% of suburb) classified as HRP and a TTIP of $9.4 million (Table 14), increase to 2,553 (17% of suburb) HRP and a TTIP of $259 million in 2070 (Table 15). This exponential increase in HRP continues to 2100 with a HRP of 10,069 (68% of suburb) and a TTIP of $1.8 bill shown (Table 16).

Table 14: Rank of the 40 suburbs with the greatest number of High-Risk Properties (#HRP) due to coastal inundation in 2040 within the state of Victoria. Alongside are corresponding counts of Moderate and Low Risk Properties (#MRP, #LRP), average and total Technical Insurance Premiums (TIP, $), count of exposed properties and percentage of High-Risk Properties (HRP%) from the suburb total.

Rank	Suburb	Exposed	HRP(%)	#HRP	#MRP	#LRP	Average TIP($)	Total TIP($)
1	Southbank	39,624	37.7	16,646	6,615	20,929	15,653	691,715,913
2	Docklands	23,517	12.9	3,270	1,363	20,675	5,384	136,250,932
3	Golden Beach	2,262	38.0	1,562	223	2,321	51,481	211,380,625
4	Lakes Entrance	1,962	26.4	1,206	130	3,235	54,930	251,084,140
5	Point Lonesdale	2,105	24.2	923	267	2,623	44,892	171,174,754
6	South Melbourne	4,926	5.7	723	77	11,902	727	9,231,864
7	Paradise Beach	634	52.1	587	8	532	156,612	176,501,877
8	Carrum	1,838	19.2	556	523	1,810	4,576	13,218,982
9	Elwood	6,267	4.7	556	812	10,452	818	9,672,006
10	Loch Sport	1,365	17.6	536	72	2,444	42,866	130,827,181
11	Port Melbourne	12,918	3.0	444	339	14,046	633	9,385,581
12	Edithvale	2,298	10.1	376	370	2,959	2,605	9,650,415
13	Queenscliff	501	23.5	372	23	1,190	54,183	85,880,540
14	Melbourne	4,520	0.3	331	673	114,911	183	21,165,798
15	Hollands Landing	301	98.3	297	0	5	310,093	93,648,098
16	Port Albert	413	65.3	293	38	118	91,740	41,191,057
17	Silver Leaves	616	40.3	257	48	333	69,312	44,221,309
18	Bonbeach	2,377	6.1	257	380	3,566	1,319	5,542,024
19	Paynesville	820	7.3	230	78	2,854	14,182	44,844,572
20	Tooradin	826	24.3	229	74	640	9,293	8,763,179
21	Seaford	5,082	1.9	229	571	11,019	404	4,769,906
22	Patterson Lakes	4,026	4.8	198	329	3,584	1,154	4,744,974
23	Raymond Island	570	28.9	196	30	452	47,808	32,413,982
24	St Kilda	1,622	0.7	163	118	22,659	140	3,210,583
25	Chelsea	3,347	2.6	148	603	4,867	527	2,958,286
26	Altona	5,199	1.7	134	112	7,700	335	2,661,272
27	Aspendale	2,170	3.5	127	451	3,059	523	1,902,144
28	Kensington	2,367	1.4	126	383	8,582	241	2,192,189
29	Barwon Heads	2,014	4.0	122	84	2,807	4,418	13,312,809
30	Eagle Point	175	11.6	107	10	808	24,652	22,803,433
31	Warrnambool	191	0.5	104	0	20,840	912	19,094,320
32	Seaholme	864	10.4	102	29	850	3,720	3,648,869
33	Seaspray	370	20.1	95	26	352	23,820	11,266,649
34	McLoughlins B	194	47.4	92	12	90	76,137	14,770,570
35	Geelong	88	1.2	86	0	7,201	3,777	27,520,000
36	Mans Beach	87	97.7	85	0	2	279,856	24,347,433
37	Weeribee South	203	4.5	78	26	1,644	1,010	1,764,947
38	Chelsea Heights	2,029	3.0	76	133	2,316	990	2,500,743
39	Point Cook	989	0.3	68	63	25,771	60	1,553,736
40	The Honeysuckles	367	15.1	67	48	328	3,561	1,577,319

Note: Alongside are corresponding counts of Moderate and Low Risk Properties (#MRP, #LRP), average and total Technical Insurance Premiums (TIP, $), count of exposed properties and percentage of High-Risk Properties (HRP%) from the suburb total.

Table 15: Rank of the 40 suburbs with the greatest number of High-Risk Properties (#HRP) due to coastal inundation in 2070 within the state of Victoria. Alongside are corresponding counts of Moderate and Low Risk Properties (#MRP, #LRP), average and total Technical Insurance Premiums (TIP, $), count of exposed properties and percentage of High-Risk Properties (HRP%) from the suburb total.

Rank	Suburb	Exposed	HRP(%)	#HRP	#MRP	#LRP	Average TIP($)	Total TIP($)
1	Southbank	39,913	72	31,672	2,637	9,881	157,735	6,970,329,127
2	Docklands	23,597	45	11,403	3,198	10,707	65,338	1,653,585,633
3	Melbourne	4,874	3	3,053	434	112,428	3,004	348,233,838
4	Elwood	7,013	23	2,757	468	8,595	31,393	371,060,187
5	Port Melbourne	14,341	17	2,553	1,607	10,669	17,492	259,384,415
6	Patterson Lakes	4,054	57	2,336	757	1,018	30,346	124,753,139
7	Seaford	6,004	19	2,271	710	8,838	13,956	164,945,245
8	Golden Beach	2,346	50	2,035	46	2,025	144,015	591,327,475
9	Point Lonsdale	2,242	49	1,881	50	1,882	121,763	464,281,829
10	Lakes Entrance	2,093	37	1,694	75	2,802	106,294	485,870,164
11	Chelsea	3,739	27	1,538	490	3,590	26,025	146,207,165
12	South Melbourne	5,489	12	1,508	771	10,423	20,449	259,745,096
13	Edithvale	2,633	39	1,444	299	1,962	51,110	189,361,787
14	Carrum	2,066	50	1,431	56	1,402	93,990	271,537,335
15	Aspendale	2,504	36	1,322	239	2,076	34,537	125,610,114
16	Bonbeach	2,711	27	1,125	280	2,798	34,727	145,958,341
17	Altona	5,783	14	1,109	794	6,043	11,897	94,530,794
18	Barwon Heads	2,397	32	950	275	1,788	39,682	119,560,366
19	Loch Sport	1,567	28	868	71	2,113	69,551	212,270,963
20	Chelsea Heights	2,235	30	747	299	1,479	21,383	53,991,751
21	St Kilda	2,542	3	744	198	21,998	3,420	78,461,645
22	Aspendale Gdns	2,732	26	707	579	1,446	7,735	21,132,125
23	Middle Park	2,727	23	614	489	1,624	8,381	22,854,632
24	Paradise Beach	642	54	613	7	507	169,734	191,290,495
25	Kensington	3,136	6	545	27	8,519	17,972	163,382,066
26	Paynesville	971	17	540	39	2,583	38,262	120,985,210
27	Silverleaves	635	75	478	36	124	176,821	112,811,730
28	Tooradin	880	49	464	80	399	100,262	94,547,019
29	Queenscliff	520	27	421	8	1,156	81,161	128,639,428
30	Port Albert	440	85	381	10	58	255,209	114,588,822
31	Raymond Island	652	53	359	43	276	126,442	85,727,587
32	Frankston	1,178	1	320	72	23,406	618	14,709,019
33	Seaholme	962	32	313	104	564	47,721	46,814,329
34	Hollands Landing	302	99	300	1	1	314,842	95,082,354
35	Point Cook	1,666	1	297	74	25,531	1,816	47,034,533
36	South Wharf	319	93	295	4	20	74,370	23,723,903
37	Seaspray	376	60	283	38	152	103,777	49,086,746
38	Williamstown	1,556	3	276	173	8,449	4,992	44,422,201
39	Ocean Grove	1,047	2	275	104	11,256	3,630	42,240,442
40	Rosebud	988	2	258	102	11,347	1,509	17,668,210

Note: Alongside are corresponding counts of Moderate and Low Risk Properties (#MRP, #LRP), average and total Technical Insurance Premiums (TIP, $), count of exposed properties and percentage of High-Risk Properties (HRP%) from the suburb total.

Table 16: Rank of the 40 suburbs with the greatest number of High-Risk Properties (#HRP) due to coastal inundation in 2100 within the state of Victoria. Alongside are corresponding counts of Moderate and Low Risk Properties (#MRP, #LRP), average and total Technical Insurance Premiums (TIP, \$), percentage increase of #HRP from 2040-2100, count of exposed properties and percentage of High-Risk Properties (HRP%) from the suburb total.

Rank	Suburb	Exposed	HRP(%)	#HRP	#MRP	#LRP	Average TIP(\$)	Total TIP(\$)	#HRP Increase 2040-100
1	Southbank	41,464	85.1	37,589	1,496	5,105	264,329	11,680,701,389	126.0
2	Docklands	23,625	83.5	21,140	1198	2,970	217,848	5,513,308,718	546.0
3	Port Melbourne	14,699	67.9	10,069	2,131	2,629	123,546	1,832,066,754	2,168.0
4	Elwood	7,726	43.9	5,185	635	6,000	99,305	1,173,787,152	833.0
5	Altona	6,185	58.6	4,655	407	2,884	119,523	949,728,042	3,374.0
6	Seaford	7,489	36.8	4,350	281	7,188	89,156	1,053,736,778	1,800.0
7	Melbourne	6,228	3.5	4,027	383	111,505	10,767	1,248,061,602	1,117.0
8	Patterson Lakes	4087	93.4	3,841	104	166	256,066	1,052,688,367	1,840.0
9	S Melbourne	6,271	29.1	3,696	430	8,576	66,961	850,542,857	411.0
10	Rosebud West	6,716	40.1	3,556	521	4,798	23,148	205,435,585	88,800.0
11	Chelsea	4,295	50.7	2847	204	2567	127,526	716,438,980	1,824.0
12	Middle Park	2,727	84.6	2,306	357	64	163,968	447,141,915	22,960.0
13	Golden Beach	2,442	54.5	2,236	28	1,842	167,181	686,447,098	43.0
14	Edithvale	2,945	58	2148	47	1,510	161,101	596,878,497	471.0
15	Point Lonsdale	2,344	55.9	2,130	28	1,655	173,171	660,299,385	131.0
16	Barwon Heads	2,660	67.7	2,040	100	873	183,107	551,700,991	1,572.0
17	Bonbeach	3,119	47.8	2,008	151	2,044	121,605	511,103,831	681.0
18	Aspendale	2,873	54.7	1,991	86	1,560	148,788	541,140,595	1,468.0
19	Aspendale Gdn	2,732	72.8	1,989	378	365	180,283	492,534,259	5,425.0
20	Lakes Entrance	2,160	43.2	1,974	27	2,570	131,823	602,562,019	64.0
21	Carrum	2,400	57.4	1,657	56	1,176	169,148	488,669,687	198.0
22	Albert Park	3,710	39	1,617	458	2,068	41,610	172,389,812	3,269.0
23	Chelsea Heights	2370	63.2	1,595	141	789	153,045	386,439,455	1,999.0
24	Loch Sport	1,724	44.4	1,356	63	1,633	119,925	366,012,624	153.0
25	St Kilda	3,548	5.6	1,289	56	21,595	14,521	333,122,784	691.0
26	Kensington	3,429	14	1,275	562	7,254	28,728	261,168,111	912.0
27	St Kilda West	2,532	39.3	995	318	1,220	42,031	106,463,446	24,775.0
28	Mordialloc	3,049	16.1	991	185	4,978	26,552	163,400,564	6,507.0
29	Ocean Grove	1,296	7.2	838	80	10,717	17,449	203,015,505	2,893.0
30	Williamstown	2,476	9.4	838	49	8,011	20,170	179,475,502	1,452.0
31	Paynesville	1,055	26.1	824	38	2,300	69,411	219,476,167	258.0
32	Rosebud	1,267	6.8	794	50	10,863	14,727	172,412,862	7,118.0
33	Seaholme	981	80.4	789	57	135	193,470	189,793,780	674.0
34	Tooradin	911	77.9	735	66	142	209,739	197,784,057	221.0
35	Point Cook	3,564	2.6	683	227	24,992	5,904	152,918,099	904.0
36	Paradise Beach	647	56.2	633	1	493	178,467	201,132,667	8.0
37	Silverleaves	638	96.4	615	5	18	289,989	185,013,145	139.0
38	Raymond Is	663	84.7	574	29	75	236,041	160,035,994	193.0
39	Moolap	1,190	28.1	574	42	1,430	65,958	134,949,616	8,100.0
40	Safety Beach	1941	10.2	535	99	4,600	15,797	82,681,120	1,063.0

Note: Alongside are corresponding counts of Moderate and Low Risk Properties (#MRP, #LRP), average and total Technical Insurance Premiums (TIP, \$), count of exposed properties and percentage of High-Risk Properties (HRP%) from the suburb total.

4.7. Case Studies and Adaptation Measures

This section shows the addresses within the regional and metropolitan case study areas that are at high-risk and their associated damage costs from coastal inundation for properties with no adaptation measures (the baseline), compared to properties with a hypothetical adaptation action in place. The four adaptation actions are to artificially elevate all properties to at least an elevation above sea level of greater than 1 to 4 metres, as a proxy for practical adaptation measures (e.g., natural and physical barriers or retreat from the coast).

In addition, the risk to an area's critical infrastructure is shown in order to capture any dependent risk or outages of operations that may be due to coastal inundation. The critical infrastructure assets, as indicated, include substations, telecommunication towers, emergency (police, fire and ambulance stations, hospitals) and education facilities (primary, secondary and tertiary).

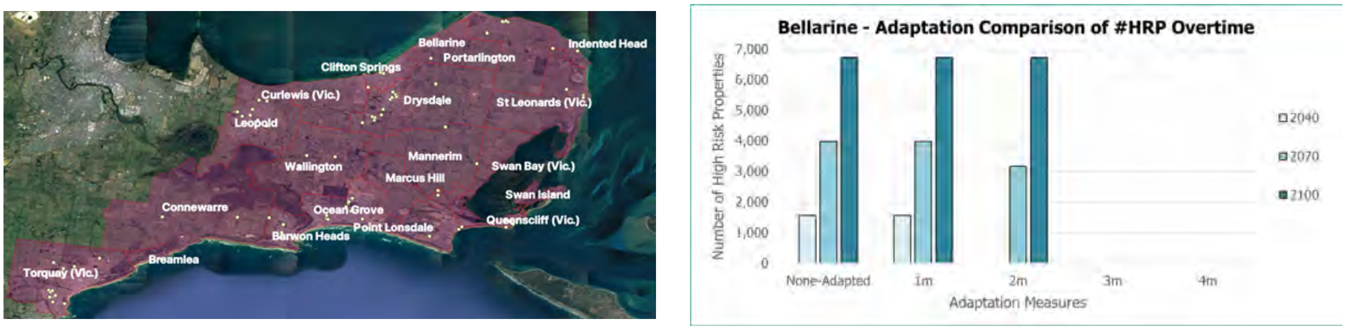
4.7.1. Bellarine Peninsula/Barwon Heads

Properties and critical infrastructure were analysed for the Bellarine Peninsula and surrounding townships (coastline toward Torquay). The 20 suburbs included are Barwon Heads, Bellarine, Breamlea, Clifton Springs, Connewarre, Curlewis, Drysdale, Indented Head, Leopold, Mannerim, Marcus Hill, Ocean Grove, Point Lonsdale, Portarlington, Queenscliff, Saint Leonards, Swan Bay, Swan Island, Torquay, Wallington (see Figure 6(i)).

Critical Infrastructure: 81 critical infrastructure assets were analysed for coastal inundation risk, including, again, substations, telecommunication towers, emergency (police, fire and ambulance stations) and education facilities (primary and secondary schools). From the 81 critical infrastructure assets identified, seven are exposed to damage from coastal inundation by the year 2100. This includes: 1 x Primary School, 3 x Fire Stations, and 3 x Telecommunication Towers.

The number of assets within each risk category are: (i) High Risk: 3 assets in 2040, increasing to 4 in 2070 and plateauing to 2100; (ii) Moderate Risk: 0 assets in 2040, 0 in 2070 and 2 by 2100; (iii) Low Risk: 4 assets in 2040, decreasing to 3 in 2070 and further decreasing to 1 by 2100 (drawn from Table 17, showing Value at Risk (VAR%)).

Figure 6: Bellarine Peninsula/Barwon Heads



i) Critical infrastructure assets

ii) Adaptation comparison of #HRP

The critical assets at risk from coastal inundation could impede on the operations of the assets and may cause them to be out of service in a damaging event. This may have a downstream impact on other assets that are reliant upon those negatively impacted.

Adaptation Measures: The Bellarine case study area's baseline/non-adapted property analysis has shown in the year 2040 that a 2 meter adaptation would reduce the #HRP by 100%. In 2070 and 2100, a 3 meter adaptation would reduce the #HRP by 100% ((Table 18), Figure 6(ii)).

A 100% reduction in TTIP is observed when a 2 meter adaptation measure is applied in the year 2040. The TTIP is significantly reduced from $284 million to $62 thousand. The TTIP observed in Bellarine Peninsular is from moderate and low risk properties.

In the year 2070, a significant change in TTIP is observed with a 3 meter adaptation applied, where the TTIP decreases from $831 million (non-adapted) to $207 million.

In 2100, a 3 meter adaptation measure reduced the TTIP by more than $1.8 billion and a 4 metre adaptation removed almost all damage costs associated with coastal inundation when compared to the non-adapted baseline analysis (Table 18 and Figure 6(ii)).

Table 17: Maximum-to-Date Value at Risk (MVAR%) to critical infrastructure within Bellarine Peninsula and surrounding townships for years 2040, 2070 and 2100.

Assets	**MVAR%**		
	2040	2070	2100
Primary School (Barwon Heads)	3.11	28.24	28.24
Fire Station 1 (Point Lonsdale)	24.09	24.30	24.30
Fire Station 2 (Point Lonsdale)	0.01	10.10	24.30
Fire Station 3 (Barwon Heads)	23.09	24.30	24.30
Telcom Tower 1 (Barwon Heads)	0.00	0.00	0.38
Telcom Tower 2 (Ocean Grove)	0.00	0.00	0.35
Telcom Tower 3 (Swan Island)	0.00	0.00	0.00

Table 18: Number of High-Risk Properties (#HRP) and the Total Technical Insurance Premium (TTIP,$) within Bellarine Peninsula and surrounding townships for the baseline analysis (non-adapted) compared to properties elevated to at least a 1m, 2m, 3m and 4m elevation above sea level, within the years 2040, 2070 and 2100

	#HRP			**TTIP ($)**		
	2040	2070	2100	2040	2070	2100
Non-Adapted	1,560	3,981	6,737	284,133,577	831,301,289	1,886,135,231
1m	1,560	3,981	6,737	188,073,504	763,562,703	1,823,680,227
2m	-	3,178	6,737	61,641	51,490,730	1,684,161,855
3m	-	-	-	-	207	2,316,618
4m	-	-	-	-	-	-

4.7.2. Wyndham

The Local Government Area (LGA) of Wyndham was selected as a metropolitan site to analyse critical infrastructure risk and to observe the outcome of hypothetical adaptation measures put forward for specific property locations. Suburbs included within the LGA analysis were Cocoroc, Eynesbury, Hoppers Crossing, Laverton North, Little River, Mambourin, Mount Cottrell, Point Cook, Quandong, Tarneit, Truganina, Werribee, Werribee South, Williams Landing, Wyndham Vale (Figure 7(i)).

Critical Infrastructure: The 172 critical infrastructure assets analysed for coastal inundation risk, included substations, telecommunication towers, emergency (police, fire & ambulance) and education facilities (primary and secondary schools) (Figure 7(i)).[6]

From the 172 critical infrastructure assets identified, five are predicted to be exposed to damage risk from coastal inundation by the year 2100. These were all within the suburb of Point Cook and include: 2 x Secondary Schools, 2 x Tertiary Institute assets, and 1 x Telecommunication Tower.

The results show the Maximum-to-Date Value-at-Risk% toward the end of the century is very low, all assets having a TTIP of less than 1. The conclusion is that coastal inundation risk is not predicted to cause any significant damage or disruption to these critical infrastructure assets.

Adaptation Measures: The focus was on individual properties and the effects of adaptation measures on the level of risk. From the 16 suburbs within Wyndham (LGA), three suburbs have properties exposed to coastal inundation in the initial analysis and by the year 2100, these suburbs had the following results: Point Cook (3,564 properties exposed in 2100),Werribee South (788 properties exposed in 2100), and Cocoroc (1 property exposed in 2100).

The adaptation analyses found that in the years 2040 and 2070, the number of HRPs

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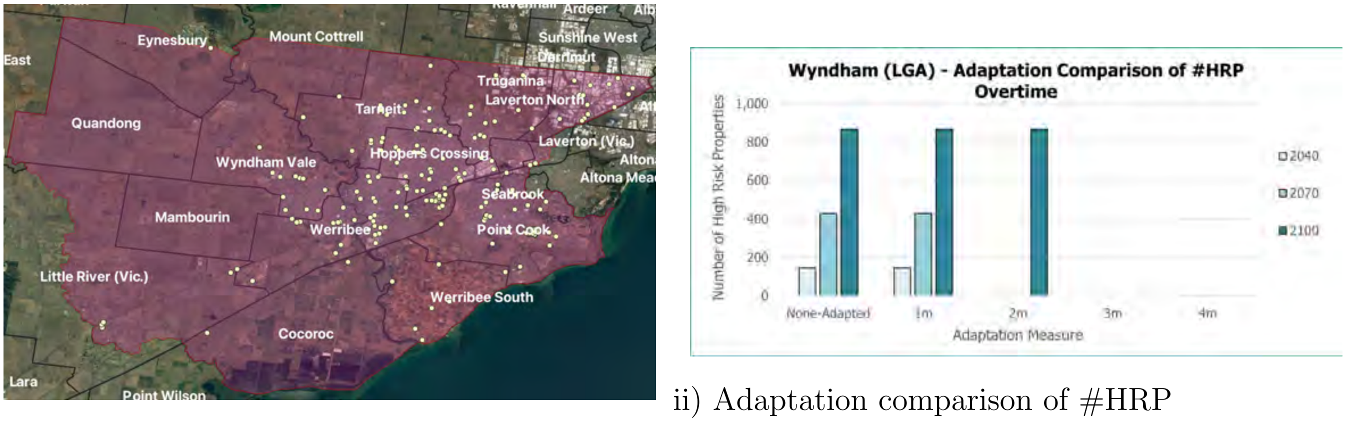
[6] Note that damage to sewage ponds and sewage treatment infrastructure is not included here, even though these are known issues for Wyndham. The impacts on utilities and reserves, among the 88 LUCs, are picked up in the UoM approach. See Tables 6–9.

Figure 7: Wyndham



i) Critical infrastructure assets

ii) Adaptation comparison of #HRP

is reduced by 100% when a 2 metre adaptation measure is applied. In the year 2100, the number of HRPs is reduced by 100% when a 3 metre adaptation measure is applied (Table 19), Figure 7(ii)).

Table 19: Number of High-Risk Properties (#HRP) and the Total Technical Insurance Premium (TTIP, $) within Wyndham (LGA) for the baseline analysis (non-adapted) compared to properties elevated to at least a 1m, 2m, 3m and 4m elevation above sea level, within the years 2040, 2070 and 2100.

	#HRP			**TTIP ($)**		
	2040	2070	2100	2040	2070	2100
Non-Adapted	147	432	868	3,638,683	82,022,133	204,342,206
1m	147	432	868	2,931,323	70,842,487	195,219,480
2m	-	-	868	4,272	1,371,156	195,219,480
3m	-	-	-	-	44	108,091
4m	-	-	-	-	-	-

4.7.3. Williamstown

The suburb of Williamstown is situated 11 km south-west from Melbourne's central business district (Figure 8(i)) with a focus on a metropolitan and highly populated area for risk analysis.

Critical Infrastructure: 13 critical infrastructure assets in Williamstown were analysed for coastal inundation risk, including hospitals, telecommunication towers, police stations and education facilities (primary and secondary schools) (Figure 8(i)). From the 13 assets identified, five have been predicted to be exposed to damage from coastal inundation by the year 2100. This includes: 1 primary school, 2 police stations, and 2 telecommunication

Figure 8: Williamstown

i) Critical infrastructure assets

ii) Adaptation comparison of #HRP

towers. The risk of these assets will increase overtime under the SLR effect (Table 20). As observed from the table, the number of assets within each risk category are: High Risk: 0 assets in 2040, 1 in 2070 and 4 in 2100. Moderate Risk: 0 assets in 2040, 0 in 2070 and 0 by 2100. Low Risk: 5 assets in 2040, decreasing to 4 in 2070 and decreasing further to 1 by 2100. Once again, the critical assets at risk of coastal inundation could impede on the operation of other dependent assets and may be out of service in a damaging event.

Adaptation Measures: For the initial non-adapted analysis of Williamstown, 2,476 properties are seen to be exposed ($VAR\% > 0\%$) to coastal inundation by the year 2100. Williamstown is ranked the 29th highest suburb based on #HRPs for 2100.

The adaptation analyses show a 2 metre adaptation measure will reduce the HRPs by 100% in 2040 and 2070. In 2100, a 100% reduction is observed from the 3 metre adaptation (Figure 8(ii), Table 21). In 2040, the TTIP of the baseline analysis reduced by 100% when a 3 metre adaptation measure is applied, more than $1.5 million. In the year 2070, TTIP is reduced by almost 100% from the baseline when a 3 metre adaptation measure is applied, more than a $44 million TTIP. In 2100, when a 4 meter adaptation measure is applied, the TTIP is reduced by $179 million from the baseline, this is an almost 100% reduction.

Table 20: Maximum-to-Date Value-at-Risk (MVAR%) to critical infrastructure within Williamstown for years 2040, 2070 and 2100.

Assets	**MVAR%**		
	2040	2070	2100
Primary School	0.00	0.00	6.50
Police Station 1	0.00	0.02	22.40
Police Station 2	0.00	0.02	19.70
Telcom Tower 1	0.18	20.00	24.30
Telcom Tower 2	0.00	0.00	0.12

Table 21: Number of High-Risk Properties (#HRP) and the Total Technical Insurance Premium (TTIP, $) within Williamstown

	#HRP			**TTIP ($)**		
	2040	2070	2100	2040	2070	2100
Non-Adapted	54	276	838	1,575,618	44,422,201	179,475,502
1m	54	268	830	1,575,488	28,518,085	168,532,830
2m	-	-	830	3,530	962,050	168,532,830
3m	-	-	-	-	40	76,719
4m	-	-	-	-	-	-

4.7.4. Hastings

The Melbourne Metropolitan suburb of Hastings (Figure 9(i)) on the Mornington Peninsula showed 705 properties exposed to coastal inundation risk (2100). 16 critical infrastructure assets were analysed and all 16 returned a low risk result. This case study focuses on the properties and various adaptation measures analysed.

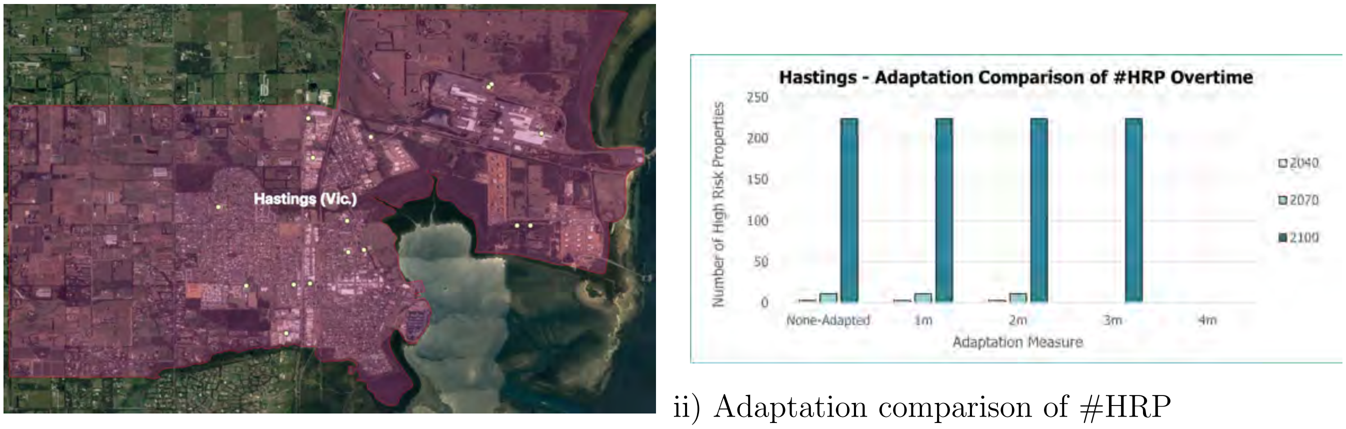
Critical Infrastructure: From the 16 critical infrastructure assets analysed, there were none at risk from coastal inundation, indicating that damage events are unlikely in this area.

Adaptation Measures: For the initial non-adapted analysis of Hastings, 705 properties are seen to be exposed ($MVAR\% > 0\%$) to coastal inundation by the year 2100. The adaptation analysis shows that a 3 metre adaptation measure will reduce HRPs by 100% in 2040 and 2070 and a 100% reduction is observed from the 4 metre adaptation option in 2100 (Figure 9(ii), Table 22).

Close to a 100% reduction in TTIP is observed when a 3 metre adaptation measure is applied in the years 2040 and 2070 from the baseline analysis. The small amount of TTIP in these years for 3 metre adapted conditions is driven by low and moderate risk properties.

In 2100, a significant reduction in TTIP is not observed until a 3 metre adaptation measure is applied, the TTIP is reduced by almost $20 million from the baseline, a 4 metre adaptation option provides a 100% reduction in damage costs (Table 22 and Figure 9(ii)).

Figure 9: Hastings



ii) Adaptation comparison of #HRP

i) Critical infrastructure assets

Table 22: Number of High-Risk Properties (#HRP) and the Total Technical Insurance Premium (TTIP, $) within Hastings for the baseline analysis (non-adapted) compared to properties elevated to at least a 1m, 2m, 3m and 4m elevation above sea level, within the years 2040, 2070 and 2100.

	#HRP			TTIP ($)		
	2040	2070	2100	2040	2070	2100
Non-Adapted	3	11	224	358,072	1,433,324	26,082,602
1m	3	11	224	121,781	1,202,693	22,092,536
2m	3	11	224	19,412	1,202,693	22,092,536
3m	-	-	224	6	2,802	7,989,750
4m	-	-	-	-	-	-

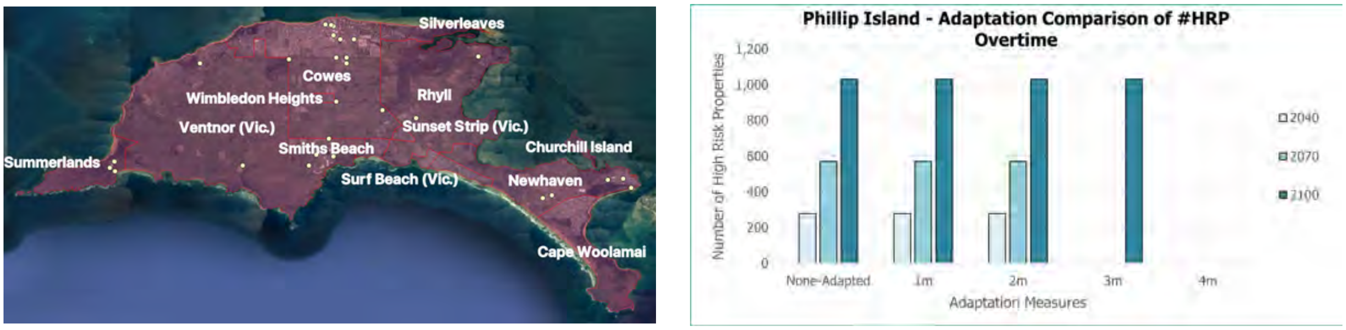
4.7.5. Phillip Island

Phillip Island is situated around Victoria's Western Port Bay, it comprises of 13 suburbs, which were analysed for coastal inundation risk (Figure 10(i)).

Critical Infrastructure: From the 23 assets identified, only one is predicted to be exposed to damage from coastal inundation by the year 2100. The critical asset's exposure to coastal inundation is seen towards the end of the century with a low low Maximum-to-Date Value-at-Risk of 0.0005%. This is equivalent to a Technical Insurance Premium below $1 (using a default replacement cost $150,000). The asset's low risk is therefore not considered to be of concern.

Adaptation Measures: Focusing on Phillip Island properties, the initial analysis showed there will be 1,661 properties exposed to coastal inundation by 2100 within 7 of the 13 suburbs in Phillip Island. These included Newhaven, Cape Woolamai, Churchill Island, Cowes, Rhyll, Silverleaves and Ventnor.

Figure 10: Phillip Island



i) Critical infrastructure assets

ii) Adaptation comparison of #HRP

The adaptation analyses show a 3 metre adaptation measure will reduce the HRPs by 100% in 2040 and 2070 and a 100% reduction is observed for the 4 metre adaptation option in 2100 from the baseline (Figure 10(ii), Table 23).

In 2040 and 2070, a 100% reduction in TTIP from the baseline is observed when a 4 metre adaptation measure is applied. In 2100, the TTIP does not decrease until a 4 metre adaptation measure is put in place, at which point almost 100% reduction in TTIP is observed from the baseline (Table 23).

Table 23: Number of High-Risk Properties (#HRP) and the Total Technical Insurance Premium (TTIP, $) within Phillip Island for the baseline analysis (non-adapted) compared to properties elevated to at least a 1m, 2m, 3m and 4m elevation above sea level, within the years 2040, 2070 and 2100.

	#HRP			**TTIP ($)**		
	2040	2070	2100	2040	2070	2100
Non-Adapted	278	572	1,032	45,903,739	129,841,108	255,112,258
1m	278	572	1,032	15,404,541	118,192,176	245,325,822
2m	278	572	1,032	9,029,695	118,192,176	245,325,822
3m	-	-	1,032	99	67,378	245,325,822
4m	-	-	-	-	-	1,896

4.8. Concluding Remarks

This study of Victorian residential and commercial property and critical infrastructure analysis of coastal inundation risk, from the Climate Risk Approach, provides an overview of at-risk properties at an asset and suburb level. It should assist decision-makers in targeting resources and prioritise location-specific adaptation and action.

Overall, the increase in risk is driven by a high-risk subset of properties that are predicted to experience significant impacts from climate change and extreme weather, while many of the remaining properties show low coastal inundation risk. The High-Risk Property results increase from 13,000 (HRP% of 0.34%) in 1990 to 152,000 (HRP of 3.91) in 2100.

The suburbs of Southbank, Docklands, and Port Melbourne contribute largely to the proportion of damage costs because of high population and a large number of properties in these areas that are vulnerable to sea-level rise. It is important to note that the damage cost figures may be understated as areas along the coast may have building replacement costs and market values above the average user.

The case study analysis found that critical infrastructure in some areas is also at risk of coastal inundation, which may result in further consequential costs to the economy due to the inability to access critical services such as water, power, and transport during extreme weather events. Various hypothetical or proxy adaptation pathways were shown to significantly reduce the coastal inundation risk to assets within the case study areas. Properties with floor heights 3 and 4 meters above sea level were most successful in decreasing the costs for the case study areas.

The risk to critical infrastructure from coastal inundation shown in the case study areas gives an insight into the increasing pressures that a changing climate will inflict on critical infrastructure and its service to populations and other dependent infrastructure. If left unadapted, critical infrastructure is projected to fail more frequently and for longer periods of time as climate change impacts worsen, and sea levels continue to rise. This will have substantial economic implications for Victoria's coastal regions. Adaptation measures are particularly important given that sea levels will continue to rise for some time, even after global greenhouse gas concentrations have been stabilised, thus damage from coastal inundation is evident in the portfolio regardless of which climate change scenario is applied.

5. Conclusion

The results from this report indicate that physical and economic damages from SLR/S surge in Victoria, across a variety of metrics, are substantial. Overall, the UoM approach uses a much larger set of LUCs than Climate Risk and, as a result, economic damages from SLR/S generate a much broader set of physical and economic losses. The two approaches, however, do roughly line up in terms of physical damages, as long as LUCs are (greatly) restricted in the UoM approach to be comparable and sea level rise in 2100 in the UoM framework (0.82m) is compared to the 2070 value (0.80m) used by Climate Risk. For UoM, restricting the LUCs to limited and existing residential and commercial properties results in physical damages to 80,090 properties in 2100. For Climate Risk, the number of high risk properties in this classification is 87,019 in 2070.

With the much broader set of LUCs, including current and vacant residential properties, commercial, industrial and agricultural land holdings and environmental and public assets, along with separately estimated land values for each of the 132 regions, in lieu of average state-wide values, the UoM approach shows that with a 5% discount rate the PV of economic losses from SLR are \$122.78 billion, \$237.40 billion, and \$337.82 billion in 2040, 2070, and 2100. Including damages from SLR/S to wetlands gives an additional PV cumulative cost from SLR/S from now to 2100 of \$46.05 billion to \$104.92 billion.

For the case of no discount rate applied to future damages from SLR/S and assuming that the growth in real asset and land values over time matches the projected growth in Victorian Gross State Product (GSP) (roughly 2% per year), the UoM approach gives (averaged) economic losses per year from now to 2040 at $9.44 billion per year, $14.77 billion per year to 2070 and $23.66 billion per year to 2100, based on the economic damages estimated from the spatial layers in 2040, 2070 and 2100. Damages from SLR/S as a proportion of state GSP are 1.90% (2040), 2.22% (2070) and 2.81% (2100), as in the case with a 5% discount rate.

Using the Climate Risk approach, with more limited LUCs, the number of properties exposed to at least some damage from coastal inundation are 174,409 in 2040, 199,331 in 2070 and 333,470 in 2100. Those properties designated as high risk increase from 33,205 in 2040 to 87,019 in 2070 and 151,755 in 2100. With base year 1990, Climate Risk shows that the total cost of damage to buildings (only) for Victoria (shown through TTIP) is expected to increase to to $2.5 billion in 2040, $15 billion in 2070 and $39 billion at the end of the century (assuming a replacement cost of $320,000 per property). Using a more broad level of damages to residential property market values, over and over replacement cost, the Climate Adjusted Value (CAV) provided by Climate Risk in the year 2040, 2070 and 2100 gives losses of $18.06 billion, $51.62 billion and $104.06 billion respectively (base case) with no increase in asset values over time. If the total market value of the property portfolio is worth almost $2.9 trillion in Victoria, the CAV is projected to force a correction to the portfolio, losing 0.6% in 2040 1.8% in 2070 and 3.7% in 2100 in value for the state as a whole.

Differences in dollar damages between the Climate Risk and University of Melbourne approaches amount to three key factors. First, to reiterate, the Climate Risk approach uses state-wide average property values. The University of Melbourne approach uses more localised, sub-regional measures of market values for asset and land values. For areas in and around Melbourne or properties near the coast with water views, this matters. Second, as indicated above, the UoM approach uses a much broader set of LUCs (even for residential and commercial properties and land areas) and does not focus solely on the replacement of damaged or existing assets. The Climate Risk approach, in other words, in terms of TTIP, largely considers damages to existing residential and commercial buildings only, not losses in land values, residential land (with no buildings of value) and vacant residential sites, or losses in reserves, conservation areas and a host of other assets. Including residential land and vacant residential sites alone, as distinct from existing residential housing, adds considerable damages to the UoM results. Third, the Climate Risk approach uses current values only and assumes no increases in asset values or land prices over time.

Overall, whatever metric is used, the UoM approach or the Climate Risk approach, the economic damages from SLR/S to coastal areas are more than enough to trigger considerable financial instability for many coastal communities and State of Victoria itself, not to mention the potential loss of life, and damages to food, water supply and environmental assets from SLR and storm surge, many aspects of which are not accounted for in our calculations. In that sense, damages outlined in this report could rightly be considered as conservative measures of the full extent of damages from SLR/S in Victoria.

It is important to close by indicating that the potential damages from SLR/S to heritage properties and traditional and cultural values were not included in this report. The impacts of coastal erosion were also not considered. A possible addendum to this report which will examine selected case studies for the relative impacts and economic damages from erosion, which will invoke significant additional losses, is being considered.

Also, for accuracy, more work needs to be done on the precise micro-impact of SLR/S on land and property values, especially those that are also subject to normal physical and economic depreciation over time, for each LUC and each specific asset across all 132 regions, as well as forming more accurate estimates of SLR/S damages on wetlands. We take both of these aspects as the subject for future research.

Appendix (1): GIS Land Use and Property Types used in the UoM Approach, CGE/GTAP Sectors and Regions

Table A1: GIS Land Use and Property Types: SLR VIC Model/UoM Approach

No	Content	Land Use Code		
		LU_1	LU_2	LU_3
	LU_1=1: Resident Properties			
1	Vacant Residential Home Site / Surveyed Lot	1	10	100
2	Residential Development Site	1	10	101
3	Vacant Englobo Residential Subdivisional Land	1	10	102
4	Vacant Residential Rural / Rural Lifestyle (0.4 to 20ha)	1	10	103
5	Detached Home	1	10	110
6	Separate House and Curtilage	1	11	111
7	Semi-Detached / Terrace Home / Row House	1	11	112
8	Separate House and Curtilage	1	11	117
9	Residential Land (with buildings which add no value)	1	11	118
10	Single Strata Unit / Villa Unit / Townhouse	1	12	120
11	Conjoined Strata Unit / Townhouse	1	12	121
12	Residential Investment Flats	1	13	131
13	Individual Flat	1	13	132
14	Short Term Holiday Accommodation	1	13	133
15	Aged Care Complex / Special Accommodation / Nursing Home	1	14	142
16	Miscellaneous Buildings on Residential Land	1	15	150
	LU_2=2: Mix-Use Properties			
17	Commercial Development Site	2	20	200
18	Commercial Land (with buildings which add no value)	2	20	202
19	Retail Premises (single occupancy/single title/single stratum)	2	21	210
20	Mixed Use Occupation	2	21	212
21	Regional / District / Neighbourhood Shopping Complex	2	21	213
22	National Company Retail	2	21	214
23	Fuel Outlet / Garage / Service Station	2	21	215
24	Office Premises	2	22	220
25	Low Rise Office Building	2	22	221
26	Residential Hotel / Motel / Apartment Hotel Complex	2	23	230
27	Tourist Park / Caravan Park / Camping Ground	2	23	234
28	Pub/Tavern/Hotel/Licensed Club/Restaurant/Licensed Restaurant/Nightclub	2	24	240
29	Member Club Facility	2	24	243
30	Health Surgery	2	27	270
31	Health Clinic	2	27	271
32	Crematorium / Funeral Services	2	27	273
33	Ground Level Parking	2	28	280
	LU_3=3: Industry & Manufacturing			
34	Industrial Development Site	3	30	300
35	General Purpose Factory	3	31	310
36	Food Processing Factory	3	31	311
37	Major Industrial Complex	3	31	312
38	General Purpose Warehouse	3	32	320
39	Open Area Storage	3	32	321
40	Petro Chemical Manufacturing	3	33	335
	LU_4=4: Quarry			
41	Quarry / Mine (open cut) Exhausted (dry)	4	40	408
42	Sand (Quarry)	4	41	410
43	Manufacturing Materials (Quarry)	4	41	412
44	Man-made Evaporation Basin	4	46	461
	LU_5=5: Mixed Farming & Grazing			
45	Mixed farming and grazing (generally more than 20ha)	5	53	530
46	Kennel / Cattery	5	54	546
47	Market Garden - Vegetables (generally less than 20ha plantings)	5	55	550

Table A1 – continued from previous page

48	Vineyard	5	56	561
49	Aquaculture Breeding / Research Facilities / Fish Hatchery	5	58	583
	LU_6=6: Utility Facilities			
50	Vacant Land	6	60	600
51	Unspecified - Transport, Storage, Utilities and Communication	6	60	601
52	Gas Transmission Pipeline	6	61	613
53	Electricity Transmission Lines	6	62	624
54	Electricity Distribution / Reticulation Lines	6	62	625
55	Hazardous Materials / Toxic Storage Centre	6	63	634
56	Sewerage / Stormwater Treatment Plant Site	6	63	636
57	Sewerage / Stormwater Pump Stations	6	63	637
58	Sewerage / Stormwater Pipelines	6	63	638
59	Water - Urban Distribution Network	6	64	646
60	Closed Roads	6	65	654
61	Reserved Roads / Unused Roads	6	65	655
62	Telecommunication Towers and Aerials	6	69	694
	LU_7=7: Education-Public Activities			
63	Early Childhood Development Centre - Kindergarten	7	72	720
64	School Primary - Public/Private	7	72	721
65	Research Institute - Public	7	72	727
66	Church, Temple, Synagogue, etc	7	74	740
67	Rectory, Mance, Presbytery	7	74	742
68	Religious Study Centre	7	74	743
69	Halls and Service Clubrooms	7	75	750
70	Community / Neighbourhood Facility	7	75	752
71	Community Service Facilities or Other	7	78	78
72	Public Conveniences	7	78	780
	LU_8=8: Outdoor & Parks			
73	Outdoor Sports - Extended Areas / Cross Country	8	81	813
74	Outdoor Sports Grounds - town or suburban facilities	8	82	821
75	Outdoor Sports - Extended Areas / Cross Country	8	82	822
76	Water Sports - Open Areas	8	82	824
77	Equestrian Centre	8	82	828
78	Bike Track / Walking Trails	8	82	829
79	Museum / Art Gallery (National/State/Regional)	8	83	831
80	Museum / Art Gallery (Local)	8	84	841
81	Wildlife Zoo / Park / Aquarium (Local)	8	84	843
82	Parks and Gardens (Local)	8	84	844
	LU_9=9: Reserve & Conservation			
83	Reserved Land	9	90	90
84	Nature Reserve	9	91	91
85	Conservation Area - Public	9	96	960
86	Conservation Area - Private	9	96	961
87	Protected Seascape - Public	9	97	972
	LU_10=10: Unidentified Use			
88	Unidentified puprpose land	U		

Source: Department of Environment, Water, Land and Planning (2020).

Appendix (2): Macroeconomic Impacts to Victoria from Climate Change

The estimated damages from SLR/S are considerable. In this section the overall damages to the State of Victoria (as a whole) from global warming under different global temperature increases are detailed, many of which also affect coastal communities. These added damages generally augment the damages from SLR/S. Our platform is a Computable General Equilibrium Model, or CGE model for short, using a GTAP database (see Hertel (1997)).

In its current form, a GTAP model (and its accompanying database) is a trade model where countries/regions can buy and sell goods and services from each other. In each country, there are several producers, each one produces a single good or service, which will be consumed domestically by regional households (final consumption) and producers (intermediate demand), or will be exported to other international regional households or producers. In the production process, producers purchase production factors (capital, land, labour and natural resources) from households and intermediate commodities from other producers. Producers maximise their current profit given inputs and output prices. Regional households earn income from selling productive factors (e.g., labour) and allocate this income on consumption expenditures and savings.

The producer price of the commodities produced in the model differs from the consumer's price due to taxes and margins (transportation, trade, insurance, etc.). Saving in the model is pooled in a global bank and set equal to (aggregated) global investment. The baseline (implicit) discount rate is 5%.

Following Kompas and Van Ha (2019) and Kompas et al. (2018), for climate change damage functions, the standard CGE producer problem is extended into a forward-looking problem, where the producer can maximise dividends (profits) over the long run. The part of the solution for the forward-looking producer problem that is different from the traditional recursive GTAP model can be summarised in terms of a system of motion equations:

$$\dot{k}_{r,t} = \psi_{r,t} - \delta_r k_{r,t} \tag{11}$$

$$\dot{\mu}_{r,t} = \mu_{r,t}[i_t + \delta_r] - \frac{\phi_r}{2}\left(\frac{\psi_{r,t}}{k_{r,t}}\right)^2 p^I_{r,t} - p^K_{r,t} \tag{12}$$

where $p^K_{r,t}$ and $k_{r,t}$ are the rental price of capital and the capital stock in region r at time t; $p^I_{r,t}$ is the price of an investment good; δ_r is the depreciation rate; ψ_r is the capital increment from the (gross) investment activity; i_t is the global interest rate; ϕ_r is an investment increment coefficient; and $\mu_{r,t}$ is the shadow price of capital.

While the capital accumulation process in a forward-looking model (Equation 11) is similar to that of a recursive GTAP model, the shadow price of capital equation (Equation 12), however, allows for a connection between future price dynamics to the producer's current period decision making. The above system of motion equations replace the conventional GTAP recursive capital accumulation and adaptive expectations formulation, converting the recursive dynamic GTAP model into a intertemporal forward-looking model. The forward looking model is an important component in evaluating climate change impacts, since these impacts are forward in time and must be anticipated beforehand.

Commodity Sectors and Countries and Regions

The CGE/GTAP model has a sub-national component for Australia, i.e., for each state and region. Commodity sectors are provided in Table A7 below for 22 different categories/sectors and region/country codes are listed in Table A8. In total there are 64 countries/regions plus 8 Australian states and territories. The regional Input-Output database for Australia provided by (Lenzen et al., 2017) is used for the modelling. There are two inputs needed from the Splitreg package: (1) the split share; and (2) the import shares for intermediate and final demand (see Horridge (2017)). As the shares will be applied to basic intermediate demands, factor incomes, indirect taxes, and even output, both the GDP share and output share can be a candidate for the split share. Import shares in intermediate and final demand are calculated from corresponding demand components provided in (Lenzen et al., 2017).

Climate Change Damage Functions

To determine the impacts of climate change the focus is on damage functions, with an emphasis on losses in agricultural and labour productivity from heat stress or temperature increases. Many other aspects or potential damages (e.g., bushfires, losses in biodiversity, floods, etc.) are thus ignored. Roson and Sartori (2016) estimate the damage function for Australia as a single country. With their damage functions, Kompas et al. (2018) show a relatively moderate impact from climate change in Australia under 1^o–4^oC warming scenarios. Nevertheless, Australia is a vast country, with different climate zones. Table A2 shows differing monthly rain falls and temperature patterns for the states and territories in Australia. The statistics in these tables are the latest 10-year averages. For each state, the (simple) average is calculated for those weather stations with sufficient recorded data. Stations with anomalous data as given in Bureau of Meteorology (2020*b*) are excluded. The monthly weather station data for Australia is available from the Bureau of Meteorology (2020*a*). With such variability in temperature (and ultimately) climatic data, quite different impacts from climate change are expected across the country.

Table A2: Climate Differences in Australia by State in the Past Decade

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
	Average Rain Fall (*mm*)												
aus_nsw	81	87	114	82	53	100	49	53	49	56	76	72	872
aus_vic	44	44	47	50	60	63	60	67	53	47	53	49	637
aus_qld	161	165	178	52	38	37	27	19	27	39	54	106	904
aus_sa	23	25	20	23	36	38	37	38	27	21	20	21	329
aus_wa	59	43	39	18	35	42	41	39	25	20	20	31	413
aus_tas	50	43	58	58	91	72	95	99	80	71	70	67	855
aus_act	51	65	66	34	23	49	32	42	51	43	68	74	598
aus_nt	242	199	140	51	12	1	8	1	11	40	90	138	934
	Average Temperature (^oC)												
aus_nsw	25	24	21	18	14	12	11	12	15	18	20	23	18
aus_vic	22	21	19	16	13	10	10	10	12	15	17	20	15
aus_qld	29	28	27	24	21	18	18	19	22	25	27	28	24
aus_sa	26	24	22	19	15	12	12	13	16	19	21	24	18
aus_wa	27	26	25	22	18	15	14	15	18	21	23	25	21
aus_tas	17	16	15	13	10	8	8	8	10	12	14	15	12
aus_act	23	21	18	14	9	7	6	7	10	14	17	20	14
aus_nt	30	29	28	26	22	20	20	21	25	28	29	30	26

*Source: Bureau of Meteorology (2020*b*).*

Agricultural Productivity

Roson and Sartori (2016) consider the impact of climate change to agricultural crop yields for maize, wheat, rice and other agricultural products separately, and for individual countries or regions as a function of their latitude. For regional Australia, with latitude data, the following equation is used to calculate the impact of climate change on maize, wheat, and rice:

$$VY(C, L) = VY(C, 0) + [VY(C, 40) - VY(C, 0)] * L/40 \tag{13}$$

where VY is the change in crop C productivity in the region with latitude L. The assumption is that the change in the above crop yields “ranges linearly from its baseline value at the equator up (or down) to its value at 40^o latitude and beyond”(Roson and Sartori (2016, p. 90)). Results are given in Table A3.

Table A3: Maize, Wheat and Rice Productivity Variation (*% change)*

	Maize					Wheat					Rice				
	+1^{o}C	+2^oC	+3^{o}C	+4^{o}C	+5^{o}C	+1^{o}C	+2^{o}C	+3^{o}C	+4^{o}C	+5^{o}C	+1^{o}C	+2^{o}C	+3^{o}C	+4^{o}C	+5^{o}C
aus_nsw	-1.59	-3.99	-5.19	-7.99	-11.59	-3.22	-5.61	-9.57	-13.14	-15.91	-3.21	-2.80	-2.40	-6.80	-14.42
aus_vic	-1.26	-3.44	-4.53	-7.44	-11.26	-4.21	-5.83	-8.14	-10.28	-12.06	-3.65	-2.91	-2.18	-6.91	-15.30
aus_qld	-2.33	-5.21	-6.66	-9.21	-12.33	-1.02	-5.12	-12.75	-19.51	-24.49	-2.23	-2.56	-2.89	-6.56	-12.46
aus_sa	-1.75	-4.25	-5.50	-8.25	-11.75	-2.75	-5.50	-10.25	-14.50	-17.75	-3.00	-2.75	-2.50	-6.75	-14.00
aus_wa	-2.11	-4.85	-6.22	-8.85	-12.11	-1.67	-5.26	-11.81	-17.62	-21.95	-2.52	-2.63	-2.74	-6.63	-13.04
aus_tas	-0.85	-2.75	-3.70	-6.75	-10.85	-5.45	-6.10	-6.35	-6.70	-7.25	-4.20	-3.05	-1.90	-7.05	-16.40
aus_act	-1.35	-3.59	-4.71	-7.59	-11.35	-3.94	-5.77	-8.53	-11.06	-13.11	-3.53	-2.88	-2.24	-6.88	-15.06
aus_nt	-2.56	-5.60	-7.12	-9.60	-12.56	-0.32	-4.96	-13.76	-21.52	-27.20	-1.92	-2.48	-3.04	-6.48	-11.84

For other agricultural crops, we follow Roson and Sartori (2016) and assume their total factor productivity is a quadratic function of temperature and linear in precipitation and CO_2 concentration:

$$DY = (115.992 + 0.4752p + 7.884k/365)DT - 9.936DT^2 \tag{14}$$

where DY is the transformed variation in crop ouput per hectare, p and k are the precipitation to temperature and CO_2 concentration to temperature ratios, and DT is the change in temperature. With localised temperature patterns, Queensland and the Northern Territory are the hardest hit regions when the global temperature increases (see Table A4). overall, given the lack of detailed GTAP commodities in the local I-O tables for Australia, the only alternative is to aggregate to 22 commodity sectors using Australian output shares (see Table A7).

Table A4: Other Agricultural Crop Productivity Variation (*% change)*

	Global Warming Scenariors				
	+1^{o}C	+2^{o}C	+3^{o}C	+4^{o}C	+5^{o}C
aus_nsw	-1.04	-2.28	-3.72	-5.36	-7.20
aus_vic	-0.58	-1.36	-2.34	-3.52	-4.90

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Table A4 – *Continued from previous page*

	+1°C	+2°C	+3°C	+4°C	+5°C
aus_qld	-2.27	-4.73	-7.40	-10.26	-13.33
aus_sa	-1.21	-2.62	-4.23	-6.04	-8.05
aus_wa	-1.67	-3.54	-5.62	-7.88	-10.35
aus_tas	0.10	0.00	-0.30	-0.79	-1.49
aus_act	-0.33	-0.87	-1.60	-2.53	-3.66
aus_nt	-2.63	-5.46	-8.48	-11.71	-15.13

Labour Productivity

To improve on the measure for labour productivity variations under local and regional climate change for Australia, our own estimation method is used for losses in labour productivity. For the rest of the world, the Roson and Sartori (2016) results are applied.

For regional Australia, a method developed by Climate Risk (climaterisk.com.au) is used. The climate driver used by Climate Risk is Wet-Bulb-Globe-Temperature. Specifically, a report by the International Labor Organisation (ILO) uses epidemiological data to derive an exposure-response relationship between the hourly Wet-Bulb-Globe-Temperature (WBGT) and worker productivity. The analysis looks at different intensities of work, however, Climate Risk focuses on the relationship for the most intense outdoor work. From this point, the impact can be scaled back to other parts of the labour force. The output is an average number of hours lost per year. To project future changes across Australia, the MPI-ESM/CLMcom model (https://cordex.org) provided through CORDEX is used. In terms of data, a representative sample of around 150,000 addresses across Australia are analysed, which represents 1% of the full set of addresses around Australia. Although this is reasonable for results at the state level, it may miss significant resolution for some rural and local areas, and since there will be a larger count in more populated areas, state averages will be skewed to where the population is located.

The first step of the analysis is to use Climate Risk models to produce the number of intense outdoor hours that are impacted for each of these addresses. This is performed using climate data to calculate hourly WBGT at present and into the future, summed across the state and the percentage of hours lost so that the total number of possible hours can be calculated. Results from every state and territory in Australia have been aggregated in this way. The final step is to reduce the total impact (depending on the extent of temperature increase and state or territory) as not all workers are working outdoors at intense hours (i.e., those that do not directly experience this high level of impact may still experience some lost productivity from heat stress). For this analysis, it is assumed that everyone working from home or in an office setting is partially impacted and that all other workplaces are at least 50% protected. The remainder of the population is exposed to high impact heat stress (when and where it occurs) during the day.

The productivity variation is estimated for each year from 2019–2100. For consistency with other countries in the model, the time series data is converted into point estimates of labour productivity damage at 1°–5°C using a linear extrapolation. Since our temperature estimates stop at 3.9°C, a damage ratio (productivity damage in percentage points to the change in temperature) of the last year in our series is used to derive the point estimate of the labour productivity loss at 5°C. From our estimated time series data, it can be seen that the ratio decreases initially and then increases and stays relatively stable as we move forward to 2100. Therefore, it is possible to use the damage ratio for 2100 as a proxy for the damage ratio at 5^{o}C. For the Northern Territory, sample population data is too limited to form reasonable estimates. Therefore, the estimated labour productivity damage results for Queensland are applied to the Northern Territory as the two states are located at relatively the same latitudes. Results are given in Table A5.

Table A5: Labour Productivity Variation (*% change)*

	Global Warming Scenariors				
	+1^{o}C	+2^{o}C	+3^{o}C	+4^{o}C	+5^{o}C
aus_nsw	-3.48	-5.59	-8.4	-11.5	-14.35
aus_vic	-1.20	-2.05	-3.13	-4.29	-5.35
aus_qld	-6.79	-10.96	-16.34	-22.39	-27.93
aus_sa	-2.92	-4.27	-5.83	-7.51	-9.40
aus_wa	-4.38	-6.14	-8.38	-10.96	-13.71
aus_tas	-0.15	-0.28	-0.49	-0.74	-0.92
aus_act	-0.78	-1.48	-2.48	-3.60	-4.48
aus_nt	-6.79	-10.96	-16.34	-22.39	-27.93

Simulation Results

With the above (climate change) damage functions for eight states/territories in Australia together with the Roson and Sartori (2016) estimates of damage functions for the rest of the world the weighted average shock for each aggregated country/region and sector with outputs as weights is calculated, for different temperature increases. Note that since Roson and Sartori (2016) provide only point estimates for the damage functions at 1^o–5^{o}C, the only alternative is to apply a linear extrapolation when the actual temperature value lies between the various ranges and then extend the linear approximation from 4^{o}C to 5^{o}C.

Table A6 shows the GSP impact for regional Australia with 4^{o}C warming. Similar *relative* results are obtained across regions and countries with lower temperature increases (see Kompas et al. (2018)). As one might expect, the Northern Territory and Queensland are the hardest hit regions in Australia. This is because of added heat stress and their proximity to the equator. Victoria is the fourth hardest hit state in Australia. The nation-wide (unweighted) average loss in GDP in 2100 is over 8%, as opposed to a loss of 1.56% in the original climate and trade model (Kompas et al., 2018), given the regional resolution and the enhanced measures of losses in labour productivity. The loss in state income in Victoria in 2095 (-3.22%) is roughly comparable to the percentage losses in GSP from SLR/S obtained earlier (see Table 11), but with the important proviso that Table 11 does not include the losses from ecosystem services.

Table A6: The Impact of Global Warming on Australian State GSP (*% change)*. Losses in Global/Country GDP are not reported here. The loss in GSP due to COVID-19 is removed.

GSP	2020	2026	2033	2041	2051	2062	2074	2081	2095	2102	2149	2202	2250	2300
	Australia													
aus_nsw	-0.01	-0.56	-1.28	-2.23	-3.43	-4.49	-5.74	-6.55	-8.30	-9.19	-13.99	-17.55	-19.04	-19.36
aus_vic	0.00	-0.20	-0.46	-0.80	-1.24	-1.67	-2.19	-2.52	-3.22	-3.58	-5.59	-7.23	-8.03	-8.29
aus_qld	-0.02	-0.99	-2.31	-4.06	-6.32	-8.29	-10.60	-12.12	-15.35	-17.02	-25.93	-32.40	-34.96	-35.37
aus_sa	-0.01	-0.47	-1.08	-1.89	-2.86	-3.59	-4.40	-4.89	-5.93	-6.46	-9.62	-12.19	-13.32	-13.59
aus_wa	-0.01	-0.55	-1.32	-2.35	-3.63	-4.52	-5.51	-6.15	-7.53	-8.25	-12.50	-15.84	-17.24	-17.54
aus_tas	0.00	-0.02	-0.06	-0.11	-0.20	-0.28	-0.36	-0.40	-0.51	-0.58	-1.15	-1.79	-2.22	-2.43
aus_act	0.00	-0.17	-0.38	-0.67	-1.05	-1.48	-2.06	-2.43	-3.23	-3.63	-5.64	-7.23	-7.97	-8.19
aus_nt	-0.02	-1.00	-2.35	-4.12	-6.40	-8.39	-10.75	-12.29	-15.57	-17.25	-26.18	-32.62	-35.17	-35.57

Table A7: Commodity Sector Name and Code: CGE/GTAP Model

ID	Sector code	Sector name
1	crp	Crops
2	daf	Dairy farming
3	als	Animal product, livestocks
4	fvo	Fruit, veg and other agricultural products
5	frs	Forestry
6	fis	Fishing
7	min	Mining
8	fpd	Food products
9	fit	Fibres, textiles, etc.
10	wpa	Wood and paper
11	fue	Fuels
12	chp	Chemicals and plastics
13	cem	Ceramics and minerals
14	met	Metals and products
15	eqm	Equipment, machinery and other manufacturing
16	uti	Utilities
17	con	Construction
18	trd	Trade, repairs and hospitality
19	trs	Transport and communication
20	fin	Finance and property
21	svg	Government, education and health services
22	osv	Other services

Table A8: Region and Country/State Name and Code: CGE/GTAP Model

ID	Country code	Country name
1	aus_nsw	New South Wales
2	aus_vic	Victoria
3	aus_qld	Queensland
4	aus_sa	South Australia
5	aus_wa	Western Australia
6	aus_tas	Tasmania
7	aus_act	Australian Capital Authority
8	aus_nt	Northern Territory
9	nzl	New Zealand
10	xoc	Rest of Oceania
11	chn	China

Continued on next page

Table A8 – *Continued from previous page*

ID	Country code	Country name
12	jpn	Japan
13	kor	Korea
14	xea	Rest of East Asia
15	idn	Indonesia
16	mys	Malaysia
17	phl	Philippines
18	sgp	Singapore
19	tha	Thailand
20	vnm	Viet Nam
21	xse	Rest of Southeast Asia
22	bgd	Bangladesh
23	ind	India
24	pak	Pakistan
25	xsa	Rest of South Asia
26	can	Canada
27	usa	United States of America
28	mex	Mexico
29	xna	Rest of North America
30	arg	Argentina
31	bra	Brazil
32	chl	Chile
33	xsm	Rest of South America
34	xca	Rest of Central America
35	xcb	Caribbean
36	aut	Austria
37	bel	Belgium
38	dnk	Denmark
39	fin	Finland
40	fra	France
41	deu	Germany
42	ita	Italy
43	nld	Netherlands
44	prt	Portugal
45	esp	Spain
46	swe	Sweden
47	gbr	United Kingdom
48	rus	Russian Federation
49	ukr	Ukraine
50	xee	Rest of Eastern Europe
51	xer	Rest of Europe
52	xsu	Rest of Former Soviet Union
53	irn	Iran Islamic Republic of
54	sau	Saudi Arabia
55	tur	Turkey
56	xws	Rest of Western Asia
57	egy	Egypt
58	mar	Morocco
59	tun	Tunisia
60	xnf	Rest of North Africa
61	xwf	Western Africa
62	xcf	Central Africa
63	xac	South Central Africa
64	eth	Ethiopia
65	ken	Kenya
66	moz	Mozambique
67	uga	Uganda
68	zmb	Zambia
69	xec	Rest of Eastern Africa
70	zaf	South Africa
71	xsc	Rest of South African Customs
72	xtw	Rest of the World

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