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# Climate Futures for Tasmania: Severe wind hazard and risk

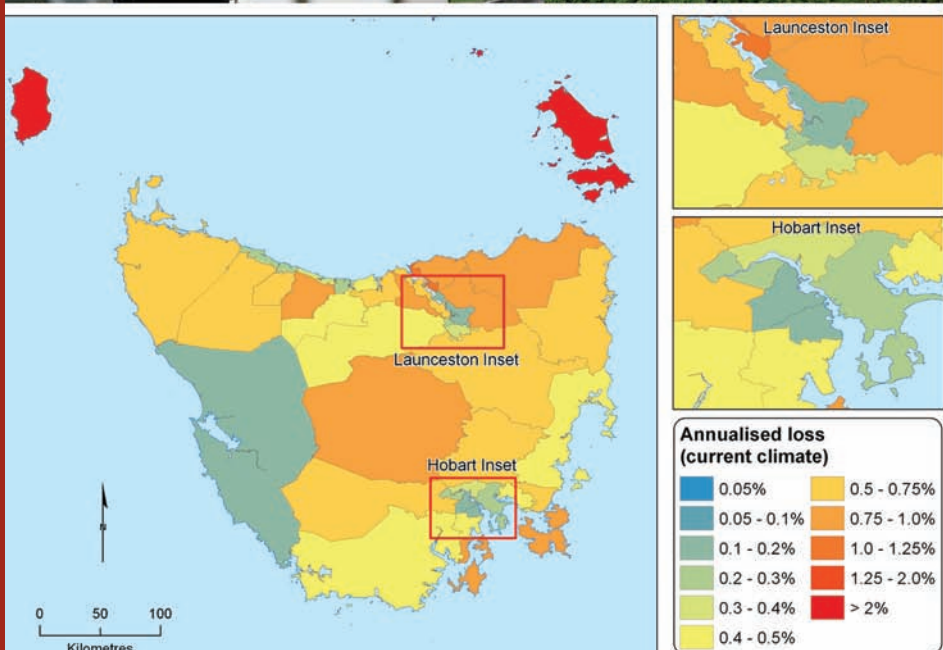
Technical Report

*Cechet RP, Sanabria LA, Divi CB, Thomas C, Yang T, Arthur WC, Dunford M, Nadimpalli K, Power L, White CJ, Bennett JC, Corney SP, Holz GK, Grose MR, Gaynor SM and Bindoff NL*

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**Australian Government**  
**Geoscience Australia**



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**COVER IMAGES**

**TOP LEFT** - Storm damage in West Hobart (January 22<sup>nd</sup> 2009): Richard Marks stands on the huge cedar in his yard that was blown over in the storm. (Photograph courtesy of *The Mercury* newspaper)

[http://www.themercury.com.au/article/2009/01/22/51051\\_tasmania-news.html](http://www.themercury.com.au/article/2009/01/22/51051_tasmania-news.html)

**TOP LEFT (below above image)** - Pedestrian wind comfort: Integration of large office or residential buildings into an existing urban structure requires a careful consideration of the impact that the buildings have on the wind field at ground level. Wind comfort and safety at pedestrian level is an increasingly important factor in the urban design process.

**TOP CENTRE** - Emergency teams are cleaning up across Tasmania after hurricane-force winds brought down powerlines, blew trees onto roads and ripped roofs off buildings (April 3, 2008). Southern Tasmania was worst-hit, with around 36,000 homes in the greater Hobart area left without power in the aftermath of the wind storms. (Hobart house damage photograph courtesy of ABC News)

[www.abc.net.au/news\\_stories\\_2008\\_04\\_03\\_2206746.htm\\_site](http://www.abc.net.au/news_stories_2008_04_03_2206746.htm_site)

**RIGHT** - Wrest Point casino and sailing vessel on the Derwent river in Hobart, southern Tasmania. (Photograph courtesy of Wrest Point casino)

**BOTTOM LEFT** - Annualised Loss (% of the value of the residential building stock) associated with 10 to 2000 year return period modelled wind hazard events (Tasmanian region). This analysis uses the Climate Futures for Tasmania modelled current climate hazard (NCEP reanalysis) for the Tasmanian region.

## Executive Summary

We have applied new modelling and analysis techniques to develop a revised understanding of the regional wind hazard across the Tasmanian region. This modelling builds on downscaled global climate simulations from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) over the Tasmanian region, undertaken by the *Climate Futures for Tasmania* project. These downscaled simulations enabled the development of wind hazard maps for the Tasmanian region for current climate and also for two climate change scenarios. Regional wind hazard was assessed by utilising the downscaled simulations and applying statistical-parametric models to derive estimates of wind hazard from two different phenomena – thunderstorms and synoptic storms.

The current understanding of severe winds for the Tasmanian region is detailed in the Australian – New Zealand wind loading standard (AS/NZS 1170.2 2011). It has been determined through statistical analysis of long-term observational records of daily maximum gust wind speeds utilising only two observing stations in the Tasmanian region (Hobart & Launceston airports) severe wind gust speeds expressed either as a return period (RP) or as a probability of exceedance within a given time period. AS/NZS 1170.2 (2011) specifies one value for the entire Tasmanian region for each return period (RP). Design wind speeds for residential housing have been set by the Building Code of Australia as the regional wind speed corresponding to the one in 500-year RP gust wind speed. This report estimates regional wind speeds utilising the downscaled climate simulations. These estimates show significant regional detail previously not available, with high RP wind speeds associated with elevated regions and low RP wind speeds with major valley regions such as the Derwent valley (south-central Tasmania). The RP gust wind speeds estimated in this study for current climate are significantly below the regional wind speeds specified in the existing Australian – New Zealand wind loading standard (AS/NZS 1170.2 2011), generally 10 to 20 percent below the design wind speeds (500-year RP gust wind hazard) confirming the conservatism of the current design standard even where observed wind gust record is available.

The RP gust wind speed assessments were used as a proxy for wind hazard in this study. In association with wind vulnerability relationships and a database describing Tasmania's residential building stock (exposure; including important attributes such as building age, roof type and wall cladding), this hazard was used to determine severe wind risk on Tasmanian residential buildings. The wind risk assessment determined the annualised loss due to severe wind hazard in urban areas across the Tasmanian region (current climate and two future climate scenarios). The assessment of wind risk driven by the small increase in the hazard during the 21<sup>st</sup> century resulted in little or no change to the wind risk associated with the current residential building stock. However, there were regional increases and decreases throughout the state. Northern Tasmania, in particular Flinders and King Islands, are likely to experience both an increase in hazard and risk. The level of risk is significantly influenced by the number of older structures within the building stock.

Australian Bureau of Statistics population projections were used to scale-up the number of residential structures based on the current ratio of residents per structure (i.e. to infer increased number of buildings with all new buildings built to the present building code). This resulted in the proportion of legacy buildings within the building population declining, and in turn a reduction in the residential building vulnerability and also in wind risk of the entire building stock. Wind risk levels during the 21<sup>st</sup> century remain well below those experienced in the northern part of the Australian continent where high wind hazard, chiefly associated with tropical cyclones, results in risk much greater than that experienced in Tasmania.

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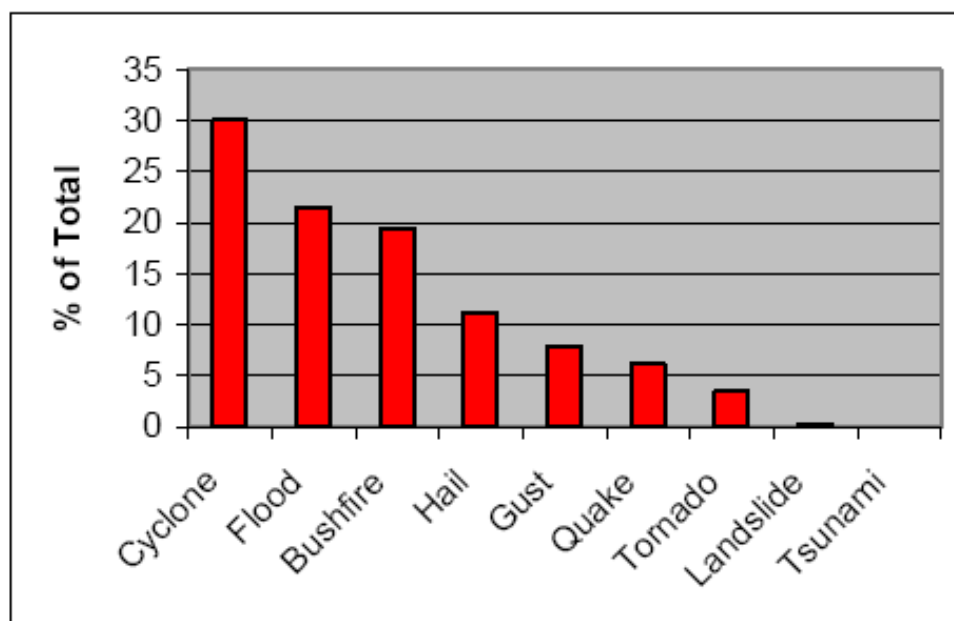


# 1. Introduction

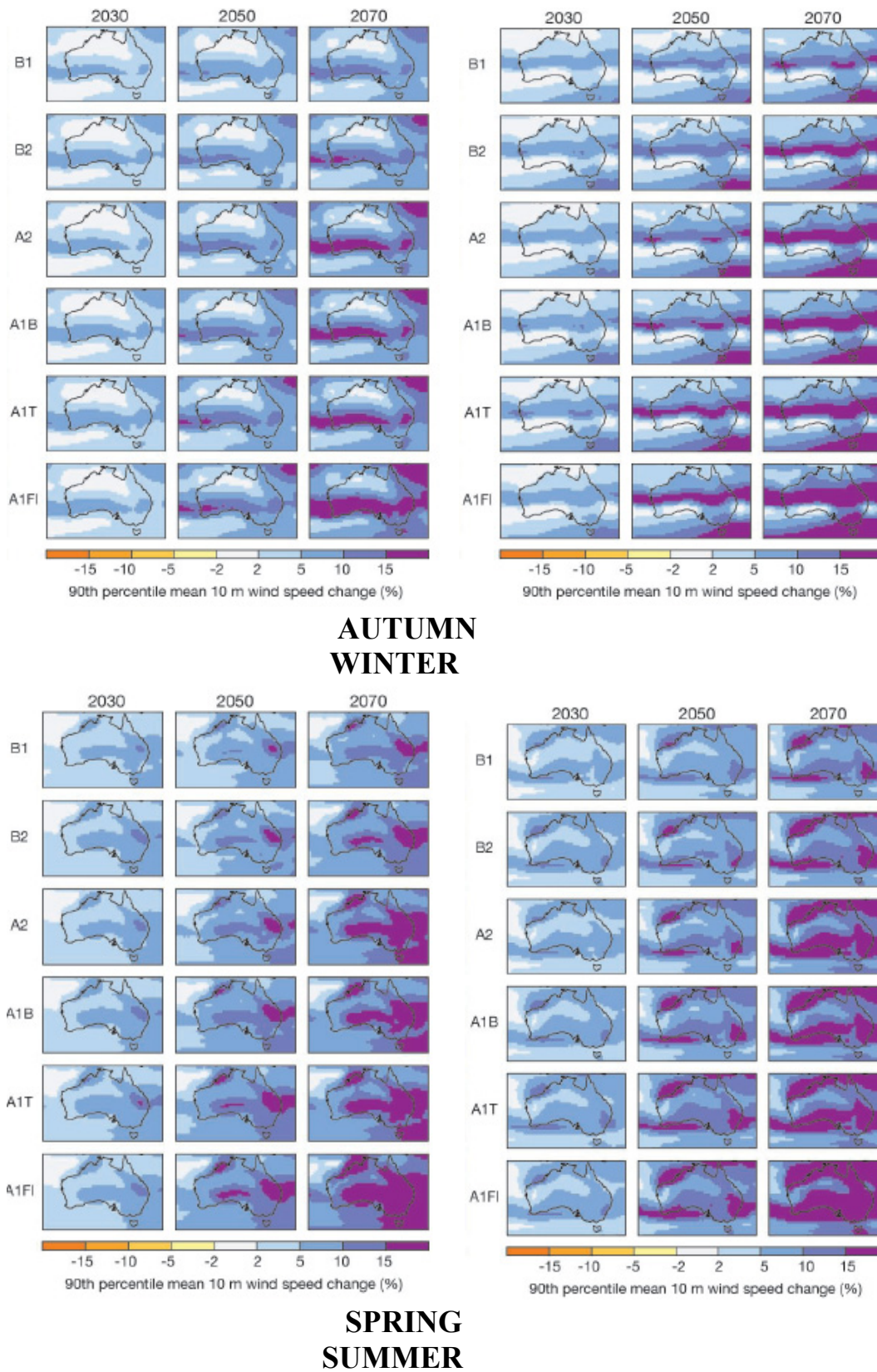
Climate change is expected to increase severe wind hazard in many regions of the Australian continent (CSIRO, 2007) with consequences for exposed infrastructure and human populations. Geoscience Australia (GA), as a partner within the *Climate Futures for Tasmania* project (funded by the Commonwealth Environmental Research Fund; CERF), has conducted a study to investigate severe wind hazard and risk to residential buildings in the Tasmanian region, both under current climate and also for two 21<sup>st</sup> century climate change scenarios. ABS population projections have also been employed to estimate the impact of the current building stock on the risk at specific future time intervals (where all new buildings are built to the current building code). The study has been established to determine the regional nature of wind hazard and risk in Tasmania, as well as to identify communities subject to high wind risk under present climate, and also those communities which will be most susceptible to any climate change related exacerbation of local wind hazard (possibly requiring an adaptation response). The study has examined trends in severe wind hazard and risk in the Tasmanian region, and has laid the foundation for the exploration of whether the community and government believe the risk is acceptable or if adaptation strategies are required.

## 1.1 BACKGROUND

Severe wind is one of the major hazards facing Australia. While cyclonic winds are the major source of wind hazard in the northern states, non-cyclonic winds driven by synoptic lows, thunderstorms and tornadoes affect the southern states. Severe winds are responsible for about 40% of damage to Australian residential buildings (see Figure 1). Over 80% of the nation’s population reside within 25 km of the coastline (Chen and McAneney 2006) and continued rapid growth in the coastal fringe, where in general the wind hazard is greater (see AS/NZS 1170.2, 2011), and is increasing the population exposed to severe winds.



**Figure 1.** Proportion of total building damage (1900 – 2003) attributed to each of nine natural hazards (from Chen 2004). Note that for cyclonic hazard losses are dominated by severe wind, however a small proportion of the loss is attributable to storm surge and flooding.



**Figure 2.** Best estimate 90th percentile mean 10 metre wind speed change (%) for 2030, 2050 and 2070 and six SRES emission scenarios (from CSIRO, 2007).

Global warming (climate change) will be expressed by significant regional and local differences in the magnitude of the warming. While the entire globe is expected to warm in the long-term, the regional differences associated with severe wind hazard in the Tasmanian region are likely to show both regional increases and reductions, driven by changes in the synoptic circulation. CSIRO climate change projections based on the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) indicate that Tasmania is one area within the Australian region that will experience an increased magnitude of severe winds (CSIRO, 2007). [Figure 2](#) shows the seasonal changes in the 90th percentile mean 10 metre wind speed for the Tasmanian region. Increases in the extremes (peak gust winds) are likely to be greater than the mean increase. The diagram suggests a greater than 15% increase in the winter, spring and summer seasons by 2070 which should be of significant concern to the community as a whole. Impacts could be expected with regard to planning, building standards, agriculture, water resources and emergency services.

## 1.2 RATIONALE

To provide a benchmark measure of severe wind hazard and risk for the Tasmanian region (current climate), this study has developed:

- (1) A detailed understanding of severe wind hazard for the Tasmanian region. Extreme winds from thunderstorm downbursts and synoptic winds were considered separately and the combined hazard assembled with regards to likelihood and severity. In addition, the regional gust wind hazard as provided by the Australian – New Zealand wind loadings standard for building design (AS/NZS 1170.2, 2011) has been used as an approximate assessment of the hazard utilised for residential building design. Here we effectively use the design standard (an engineering estimate of the upper envelope of the wind hazard) as a first estimate for the resilience in the building stock (where resilience is a measure of the difference in the damage/loss consequences between the design hazard and the actual hazard).
- (2) An understanding of residential building exposure underpinned by the National Exposure Information System (NEXIS) developed by Geoscience Australia. Specific knowledge of the type, age and construction of residential buildings varies greatly in different parts of the continent; in general capital city regions have the best data but there is significant differences in the quality and quantity of the information between major cities and between urban and rural communities. High quality residential building information was obtained from the Tasmanian Valuer Generals Office and NEXIS was utilised to complete the dataset (including missing values) through a range of assumptions detailed later.
- (3) an understanding of wind vulnerability (how severe wind hazard relates to impact/damage) for each of the residential structural types and ages considered. These vulnerability relationships were developed by Geoscience Australia through a series of expert workshops, analysis of wind damage data, and a survey of skilled damage assessors within the Australian wind engineering community.

To provide a measure of Tasmanian severe wind risk for both current climate and two climate change scenarios, this study has developed:

- (1) an understanding of severe wind hazard for two climate change scenarios separately considering thunderstorm downbursts and synoptic winds and then combining the elements to construct hazard with regards to likelihood and intensity for the region. The outputs of general circulation climate models were forced by two increasing greenhouse gas trajectories (A2 and B1 scenarios) to give representative wind hazard for the respective possible future greenhouse gas concentrations scenarios;
- (2) an understanding of how residential building exposure may change for the region utilising the Australian Bureau of Statistics population projections (Series A, B & C) and the National Exposure Information System (NEXIS) to project current trends in occupancy statistics; and

- (3) a preliminary understanding of annualised loss due to wind exposure for urban areas within 43 Tasmanian regions (considering 10 year to 2000 year return period hazard). Regions have been ranked on the severity of loss, and key contributing factors driving the risk in these high wind risk regions are considered.

The need to consider climate change adaptation options with regards to severe winds will be informed by the outputs of this study. Damage to residential buildings from severe winds is a significant concern to decision-makers in planning, building codes, construction, emergency services, and the insurance industry, as well as the community as a whole.

**Section 2** of this technical report presents the methodology employed to analyse the direct impact and risk of severe wind hazard on Australian communities. This involves the parallel development of the understanding of wind hazard, residential building exposure and the wind vulnerability of residential structures.

**Section 3** presents both the methodology to determine wind hazard from the suite of models provided by the *Climate Futures for Tasmania* project, as well as the results of the modelled regional hazard assessment. Comparison of the modelled hazard (current climate) with that inferred from AS/NZS1170.2 is also undertaken, as well as considering possible changes to the AS 4055 structural design classification for future climate.

**Section 4** presents the results of the wind risk assessment (current and future climate) as well as an assessment of the impact of population projections on the future wind risk. An assessment of casualties and death associated with severe wind events is also undertaken for current climate.

**Section 5** discusses the findings, the key contributing factors driving wind risk, as well as the limitations of the risk methodology. In addition, the need to implement strategies for mitigation of the risk is considered. Details of the location, description and availability of outputs from this work are also discussed.

**Section 6** provides conclusions regarding both the severe wind hazard and risk for the Tasmanian region.

### **1.3 UNDERSTANDING AND MANAGING RISK AND REDUCING LOSS:**

Severe wind is an expected and regular occurrence in most parts of the Australian continent. Losses associated with the majority of these events are small to negligible. Managing the risk and reducing significant loss to residential structures is a shared responsibility between:

- Australian Government
- State Government
- Local communities (Local Government)
- Individuals (property owners).

#### **Australian Government**

The Australian Government, through the Australian Building Codes Board (ABCB), has responsibility for maintenance of the Building Code of Australia (BCA). The BCA establishes performance requirements that buildings must satisfy when subjected to the actions of, among other hazards, severe winds. In relation to wind actions, the BCA references two Australian Standards to establish the performance requirements – AS/NZS 1170.2:2002 *Structural design actions Part 2; Wind actions* and AS 4055:2006 *Wind loads for housing*.

For design of engineered and residential buildings, the Australian Standard/New Zealand Standard 1170.2:2002 *Structural design actions Part 2; Wind actions* sets out the gust wind speeds that relate to the performance levels specified in the BCA. These wind speeds must be used in calculating loads

on structures in different regions of the country, across a range of sites (e.g. medium-density urban, open country, or on sloping sites). Design wind speeds are specified in terms of the wind speed associated with a particular return period, and the levels are set in an effort to equalise the risk between the low and high hazard regions across the country. [Section 2.2](#) provides further information regarding the wind loading standard. The Standard is chosen so that a new building designed and constructed to resist the wind hazard will have an acceptably small probability of failure over its lifespan. This compromise involves acceptance of the inevitability of some loss. Legacy buildings that do not comply with modern standards, and older buildings that may have suffered decay over time, typically have higher probabilities of failure than modern, code-compliant buildings. Furthermore, if the wind hazard changes over time, even houses compliant with current standards may acquire an unacceptably high probability of failure over its lifespan.

*Australian Standard 4055-2006 Wind loads for housing* provides a simplified methodology for assessing wind forces on houses. This Standard takes into account the local hazard factors (see [Section 2.2](#)) and expresses the wind hazard as a single wind class (N1 to N6 for non-cyclonic regions and C1 to C4 for cyclonic regions). This wind class is in turn used by other standards (e.g. *Australian Standard 1684.2-2006 Residential timber-framed construction*) to prescribe requirements for house framing or other elements.

### **State Government**

The State Government plays a role in providing broad planning guidelines and has responsibility for emergency management.

### **Local Communities (Local Government)**

In each State and Territory, the Building Code of Australia (BCA) forms part of the building regulations, enforced through legislation and administered at Local Government level.

### **Individuals (property owners)**

With regards to severe wind in the Tasmanian region, appropriately designed, constructed and maintained buildings can offer protection to people during most events, reducing the likelihood of injury and death. Individual property owners play an important part in reducing risk by ensuring that residences are maintained by conducting inspections (every one to three years) which can provide information regarding whether the structural strength is compromised by issues such as rot and pest infestation.

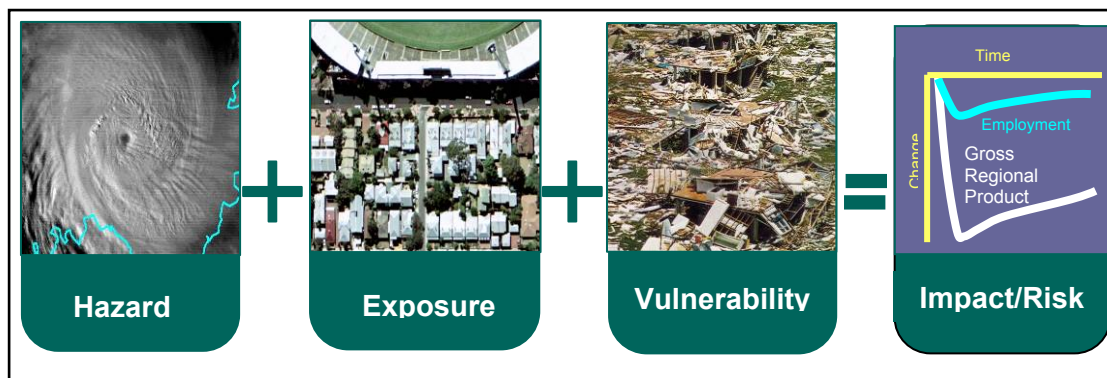
Planning for protection of residential housing does occur at all levels. There is a continuum of planning from Federal to State/Territory level, through local government, to business owners, community members and householders. Managing the risk and reducing significant loss to residential structures is a shared responsibility.

## 2. Methodology

### 2.1. SEVERE WIND RISK ASSESSMENT

Geoscience Australia has developed a methodology for wind risk assessment. The methodology was developed through extensive review of the risk literature, the development of an understanding of residential building exposure (underpinned by the National Exposure Information System; NEXIS), as well as the development of a broad understanding of wind vulnerability (how severe wind hazard relates to impact/damage) for each of the residential structural types considered. Geoscience Australia has also developed a methodology for assessing severe wind hazard (frequency and intensity), and has produced a preliminary Australian severe wind hazard map (current climate) for a range of return-period levels (Cechet *et al.*, 2010).

The approach starts with the assessment of severe wind return-period hazard, representing the natural events that cause damage to communities. Severe wind gusts arise from a wide spectrum of storms, including tropical cyclones, thunderstorms and synoptic storms. Exposure, or exposed elements can refer to people, buildings, infrastructure, crops, or the natural environment. Geoscience Australia has developed the National Exposure Information System (NEXIS) to collate exposure information at a national level to assist in managing the risk associated with natural and human-induced hazards, infrastructure failures and threats. NEXIS provides information not only on the numbers of buildings exposed, but also the types and ages of buildings and their spatial distribution—essential for evaluating the vulnerability of an area at risk. The exposure and vulnerability elements (both structural and community) are combined with the hazard to provide estimates of the impact from a single severe wind event and risk from a portfolio of events that describe possible extreme conditions over a very long length of time. A graphical representation of the risk assessment approach is shown in Figure 3. This technique provides estimates of the impact of a single hazard event and/or the risk from a representative portfolio of wind hazard events, quantified as direct economic losses.



**Figure 3:** Risk assessment approach utilised for evaluating risk from severe winds. The hazard (represented here by tropical cyclones) is evaluated and applied to the exposed elements (in this case residential buildings), through the application of suitable vulnerability relationships.

#### 2.1.1 SEVERE WIND HAZARD

Throughout this report, the term “wind hazard” is used to describe the peak wind gust of 3-second duration, measured at 10 metres above the flat open ground level. Different gust wind speeds will have different recurrence periods (or probabilities of occurrence in a given year); lower gust wind speeds will have shorter recurrence periods than higher gust wind speeds. For a given gust wind speed, the recurrence period will vary around the nation depending on the wind climate for a particular region. Thus a gust speed of 170 km/h could be expected to occur once every 20 years in

coastal north Queensland, but similar winds are only expected once in every 2000 years in the Tasmanian region. Wind speed measurements are usually recorded at sites with open, flat terrain, for example airports. However, the level of damage inflicted on a building by severe winds is related to the gust wind speed at that building's height and location. Typically, the gust wind speed at a particular building's location will vary from that recorded at an open site; the variation being caused by a number of factors. These local influences on the wind speed, such as topography and approaching terrain roughness (e.g. nearby vegetation and adjacent buildings), are incorporated into calculations of damage through local wind speed multipliers that relate the regional gust wind speed to that experienced by the building in question. In this study of Tasmania, two sources of severe wind gusts are examined – thunderstorm downbursts and synoptic storms. For each of these phenomena, stochastic models have been developed that can replicate the distribution of historical events, but provide the capability to generate the equivalent of many thousands of years of severe wind events. From these synthetic events, it is possible to derive robust statistics on the probability of occurrence of events ranging from small severe wind events that occur almost every year, through to catastrophic events that may occur only once every thousand years.

### 2.1.2 EXPOSURE

As described above, exposure refers to elements at risk from a hazard including residential buildings, people, infrastructure, industries, crops, or natural habitats such as forests or reef systems. In this study, we are concerned only with the impact of severe wind gusts to residential buildings in the Tasmanian region. It is imperative that future research on severe wind risk should include other infrastructure and assets such as commercial and industrial buildings, agricultural crops, and power and telecommunication networks to ensure a complete understanding of the risk from severe winds.

Exposure, when referring to elements in the built environment, can be defined in a building-specific format, where each individual structure in the community is identified and characteristics such as geographic location, age, wall type and roof type are known. Alternatively, a statistical definition can be used, where the numbers of buildings in a specified area is known, and their distribution amongst a range of types is also known. In the former situation, we require high-resolution information on the level of hazard at the location of each building. The latter definition allows the use of more generalised information, which is representative of the sampled area.

### 2.1.3 VULNERABILITY

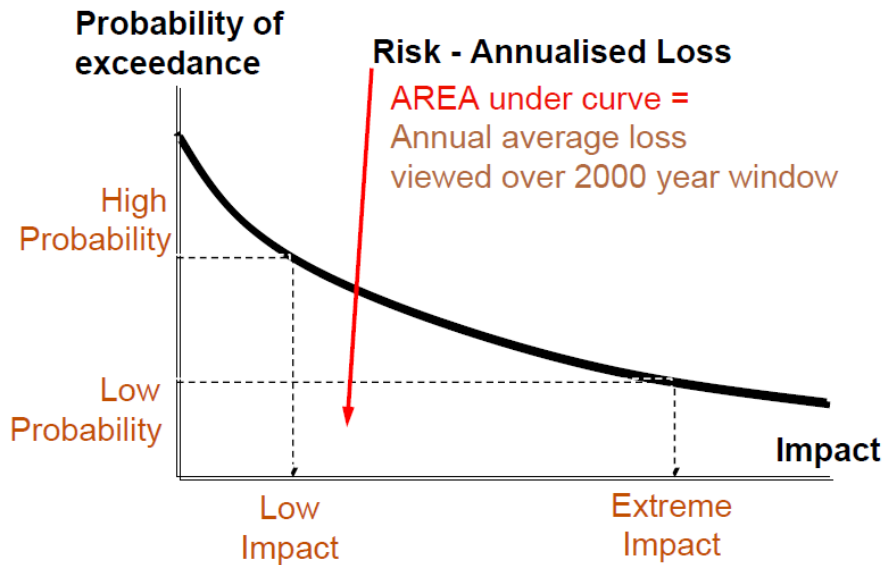
Vulnerability is the third leg of the paradigm that underpins the risk analysis. Vulnerability describes the capacity of exposed elements (buildings, infrastructure or people) to withstand, and recover from, the impact of hazards. For this study, where only direct impacts to residential buildings are considered, the vulnerability relates gust wind speed to the *damage ratio*, the repair cost divided by the replacement cost, for the particular type of building in question. The closer the damage index is to one, the more heavily the building population is damaged. It is important to note that within the built environment each building will have significant variations in building geometry, construction quality, maintenance and orientation to wind, with each permutation possessing its own vulnerability. Thus a vulnerability curve due to its empirical nature, describes the average vulnerability of a population of buildings of a similar type, not individual buildings.

### 2.1.4 RISK EVALUATION

The general methodology applied by Geoscience Australia to impact analyses is a convolution of hazard, exposure and vulnerability, to yield impact (see [Figure 3](#)). Each element is required to ensure comprehensive and integrated assessment within a consistent framework.

For each return-period hazard level, the potential for residential building damage is linked to the hazard through the vulnerability relationship for the structure type under consideration. [Figure 4](#) displays the relationship between the probability of a severe wind hazard event and the direct impact

(damage/loss) to residential structures. This Probable Maximum Loss (PML) curve depicts the interaction of severe gust wind speed, building exposure and vulnerability, and is obtained by interpolating discrete probability-loss values to obtain a curve. The losses represented by the curve range from frequent minor losses through to those associated with catastrophic events having disastrous effects. Annualised loss, which is evaluated by integrating the area under the PML curve, represents the average annual cost due to exposure to the hazard viewed through a very large length of time (time window of 2000 years was adopted for this study). The consideration of the annualised loss provides a metric to compare risk between regions.

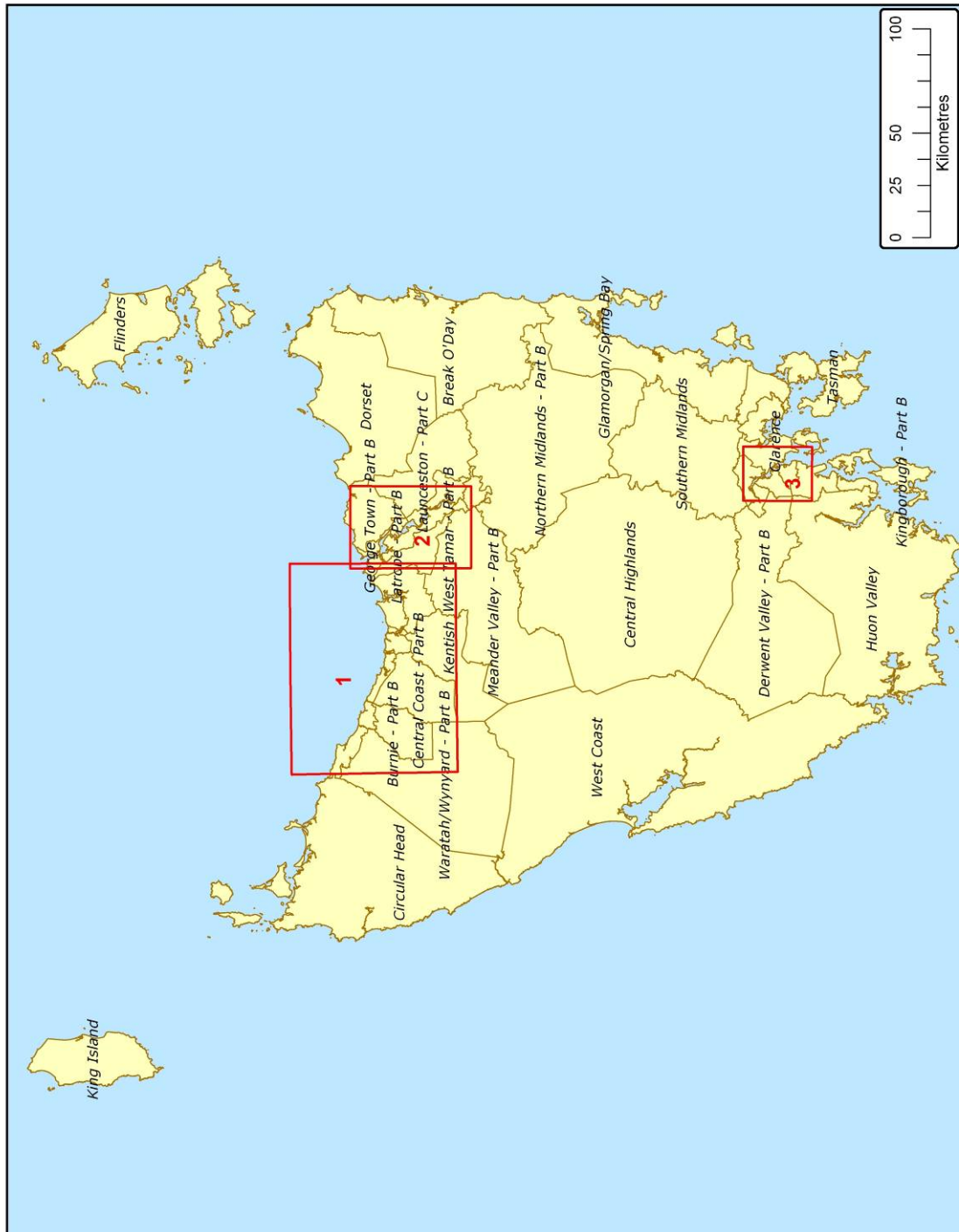


**Figure 4.** Probable Maximum Loss (PML) curve which relates the probability of exceedance of a severe wind event to the potential loss associated with that event. Discrete hazard levels are considered and then the PML curve is characterised by interpolation between the points.

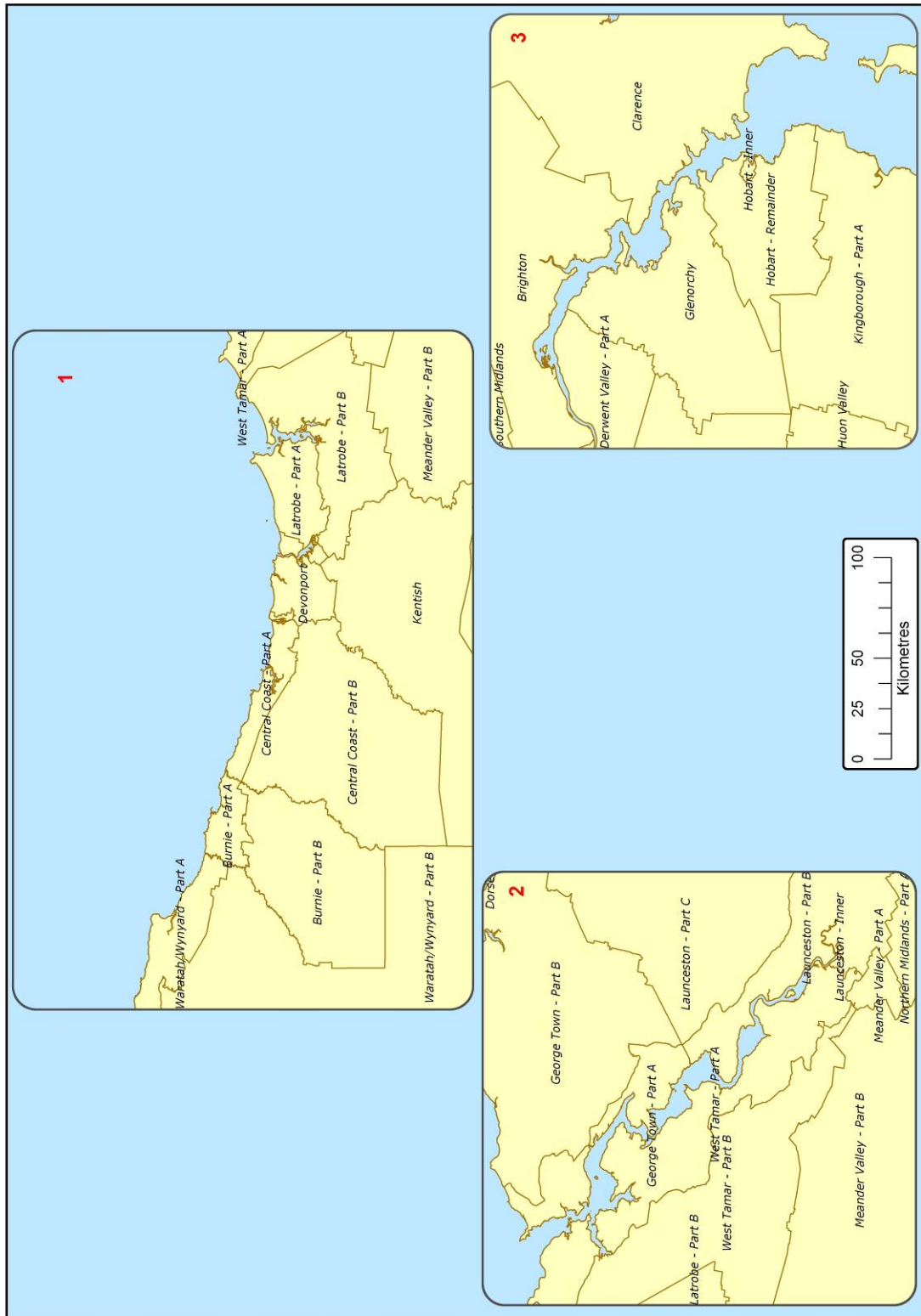
A PML curve can represent the loss distribution at any resolution, ranging from a single asset or location to a region or country. In this study, losses are assessed at the scale of the Statistical Local Area (SLA). [Figure 5](#) provides a graphical representation of all the Statistical Local Area (SLA) regions for which the wind risk has been aggregated in this report.

[Appendix 1](#) utilises the Hobart region to provide a graphical representation of the outputs for each stage of the risk assessment; wind multipliers, wind hazard and wind risk.





**Figure 5 (Part 1).** Map of Statistical Local Areas (SLA's) depicting the 43 regions for which loss was aggregated for the severe wind risk assessment. The full list of SLA names is shown in [Appendix 2](#).



**Figure 5 (Part 2).** Map of Statistical Local Areas (SLA's) – 3 INSETS shown in Part 1, which show the regions for which loss was aggregated for the severe wind risk assessment. The full list of SLA names is shown in [Appendix 2](#).

### 2.1.5 ASSUMPTIONS

Throughout the risk assessment process a number of assumptions are made, due to a range of issues surrounding climate and population projections, data quality and resolution.

The regional hazard assessment (current climate) is underpinned by gust wind speed measurements made at three Tasmanian airports (Hobart, Launceston and Wynyard) amounting to 124 years of observational record.

This study uses residential housing information obtained from the Tasmanian Valuer General's Office. This information relating to attributes such as building age and construction type have not been verified. Where this information was incomplete, we have made assumptions based on the nearest neighbours.

The vulnerability relationships were derived by employing a heuristic (knowledge-based) approach utilising the survey responses of 10 experts in the wind engineering field. Their knowledge was chiefly based on large number of events where little damage occurred and tens of events where significant damage occurred. It should be noted that the uncertainty in the vulnerability relationships increases with wind speed, and is very uncertain at very high wind speeds (these wind speeds have not been observed in the Tasmanian region). For the Tasmanian A3 region (see [Figure 6](#)), there is little difference between the hazard associated with a 1 in 100 year and a 1 in 2000 year event (see [Table 1](#); compare with cyclonic region). Therefore a very large proportion of the risk associated with severe wind in the Tasmanian region is due to events with a return period less than 100 years.

For future risk projections, population growth is treated in a simplistic manner; there is no expansion of urban areas, and the increased population is contained in the same style of urban area (e.g. low-density urban areas remain low-density). We assume no changes to construction methods, or to wind zone classifications. Existing housing is not gradually replaced by new structures (i.e. so-called knockdown rebuild option). The wind vulnerability relationships are maintained static for life of the buildings (i.e. there is no allowance for building deterioration).

The PML curves were obtained by aggregating losses across a region where hazard over the whole region is equivalent to the statistical return-period for the severe wind. This statistical approach considers hazard which has a footprint similar to the size of the region (as well as a uniform hazard across the region). An event-based risk assessment considers events with probability ranging from frequent low impact events (e.g. events that occur about 1 in 5 years) to rare extreme impact events (events that occur about 1 in 500 years). Events have very different impact footprints dependent on their intensity and nature, and for some wind hazards the gust wind speed varies markedly across the footprint (i.e. tropical cyclones). The statistical approach utilised here, which does not model actual events and therefore does not consider spatial correlation, tends to spread the impact over a broad footprint. Research in earthquake risk comparing statistical and event-based approaches (Patchett *et al.*, 2005) has indicated that statistically defined hazard yields higher assessments of risk than those from natural hazard event based simulations. Consequently, the PML curves developed here are conservative, ie estimate severe losses to be more frequent, compared to those that would be derived utilising an event-based approach.

Due to these assumptions there are limitations to the results presented in this report. The limitations mainly relate to the use of the information at high spatial resolution (buildings level) as well as to the wind vulnerability relationships and how they have been utilised for specific buildings. The accuracy of information for single buildings cannot be relied upon, whereas the aggregation to neighbourhood or Australian Bureau of Statistics meshblock regions (usually greater than 30 buildings) will reduce the impact of the assumptions on the derived information.

## 2.2. REGIONAL HAZARD ASSESSMENT

While there is significant uncertainty on how the likelihood and intensity of extreme winds will be influenced by climate change, the understanding of current regional wind hazard for the Australian region is also in need of improvement. Our understanding of “current-climate” Australian severe wind gust hazard is based on the statistical analysis of extreme wind gust observations. Observations include peak 3-second wind gusts captured at a small number of meteorological measurement stations, mainly located at significant city and regional airports. These provide a poor spatial representation with regard to wind hazard. Estimation of wind hazard has been tackled in two ways:

- (1) We use the statistical analysis of observations combined with engineering judgment in the form of the Australia – New Zealand Wind Loadings Standard (AS/NZS 1170.2, 2002) as our baseline “wind hazard map”. The AS/NZS 1170.2 is utilised by the Australian Building Codes Board (ABCB) for residential building design. In most regions of the Australian continent this is known to be a conservative assessment of the actual wind hazard, i.e. a higher hazard than what would be suggested by statistical analysis of the observations. Its use in the wind risk assessment here is likely to overestimate the risk to some degree.
- (2) We use numerical model output to develop an understanding of regional hazard for both current climate and future climate scenarios. The hazard for current climate is estimated based on a reanalysis of the later part of the 20<sup>th</sup> century (1961-1990). Future climate hazard estimates use the same models forced by greenhouse gas concentrations for the 21<sup>st</sup> century.

Regional wind hazard does not accurately depict the gust winds experienced in a residential housing environment, and therefore need to be further refined to derive the local wind hazard by considering the local terrain, topography, and the shielding provided to a structure by neighbouring structures (see [Section 2.3](#)).

### 2.2.1 AUSTRALIAN – NEW ZEALAND WIND LOADINGS STANDARD (AS/NZS 1170.2)

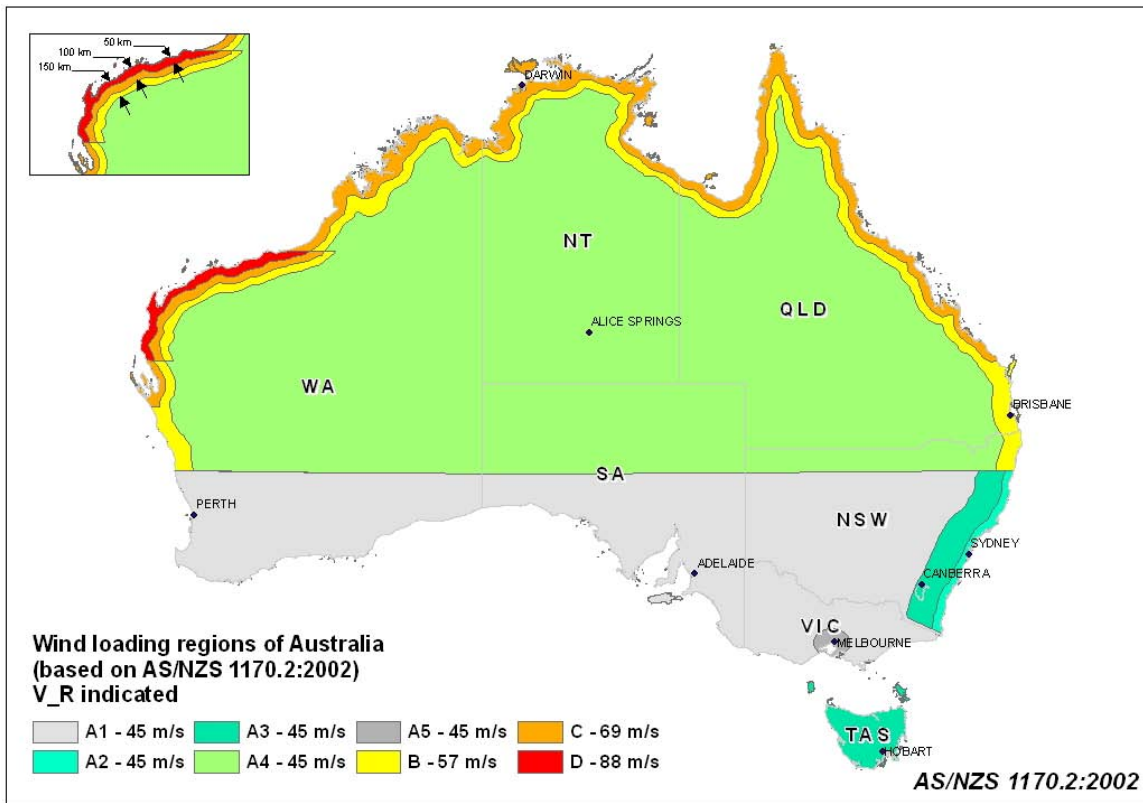
Forces exerted by wind on buildings are proportional to the square of the wind speed at the location and height of the building. Typically, the wind hazard is specified by the 3-second gust wind speed at 10m height over flat open terrain. The change in wind speed from flat open terrain and to the actual building site and from 10m height to the height of the building’s roof is taken into account during the calculation of the wind forces. The regional wind speed (i.e. 3-second gust wind speed at 10m height) is defined in the wind loadings standard AS/NZS 1170.2 *Structural design actions Part 2; Wind actions*. The standard also provides information regarding the following list of factors which can be used to define the design wind speed at a specific location:

- (a) regional location within Australia;
- (b) the probability of exceedance within the building’s life;
- (c) the roughness of the terrain within which the building is sited;
- (d) the regional variation of wind speed with wind direction;
- (e) the shape of the topography around the building and
- (f) the presence of upwind structures that may shield the building from wind.

To define regional variations in wind speeds, Australia is divided into regions A, B, C, D, within which the wind speed is broadly similar with all other factors being equal. [Figure 6](#) is an extract from AS/NZS 1170.2 that spatially defines the four regions. The regional wind speed decreases from region D down to A. Regions C and D are those where the hazard is dominated by tropical cyclones, region A (which includes the Tasmanian region) is affected by synoptic and thunderstorm downburst winds only and region B is an intermediate region. Region A is subdivided to reflect regional variations in directionality of severe winds (A1 to A7 regions).

In general, increasingly high (extreme) wind speeds have a decreasing probability of occurrence. Furthermore, the longer a building exists the more likely it is to be exposed to a given severity of wind. Hence, structures that are expected to be serviceable for longer periods of time (e.g. bridges), or structures for which the community has a greater expectation of being serviceable after a storm

(e.g. hospitals) are designed for higher wind speeds. These wind speeds are expressed either as a return period or as a probability of exceedance within a given time period. The Building Code of Australia specifies that residential buildings be designed for wind speeds with a 1 in 500 probability of annual exceedance, i.e. a return period of 500 years [BCA Table B1.2b].



**Figure 6.** Wind loading regions of Australia based on information extracted from Fig. 3.1 AS/NZS 1170.2, 2011. – (the information is identical to that contained in AS/NZS 1170.2, 2002). Tasmania is in Region A as is the majority (about 70%) of the Australian continent. The coastal region (Regions B, C & D) are associated with a higher wind hazard.

Table 1 (taken from from Table 3.1 AS/NZS 1170.2, 2011) provides the regional wind speeds for regions A, B, C & D depicted in Figure 6. Notice that for the cyclonic regions (C and D), AS/NZS1170.2 include additional factors ( $F_C$  and  $F_D$ ) which for ultimate limit wind speeds as follows:  $F_C = 1.05$  &  $F_D = 1.1$ . These additional factors allow for uncertainties in the hazard determination.

**Table 1.** Regional gust wind speeds for the regions depicted in Figure 6 for return period wind gust hazard ranging from 5 to 2000 years (from Table 3.1 AS/NZS 1170.2, 2011).

REGIONAL WIND SPEED (m/s)	REGION				
	NON-CYCLONIC			CYCLONIC	
	A(1 TO 7)	W	B	C	D
$V_5$	32	39	28	$F_C$ 33	$F_D$ 35
$V_{10}$	34	41	33	$F_C$ 39	$F_D$ 43
$V_{20}$	37	43	38	$F_C$ 45	$F_D$ 51
$V_{25}$	37	43	39	$F_C$ 47	$F_D$ 53
$V_{50}$	39	45	44	$F_C$ 52	$F_D$ 60
$V_{100}$	41	47	48	$F_C$ 56	$F_D$ 66
$V_{200}$	43	49	52	$F_C$ 61	$F_D$ 72
$V_{500}$	45	51	57	$F_C$ 66	$F_D$ 80
$V_{1000}$	46	53	60	$F_C$ 70	$F_D$ 85
$V_{2000}$	48	54	63	$F_C$ 73	$F_D$ 90
$V_R^*$	$67 - 41R^{-0.1}$	$104 - 70R^{-0.045}$	$106 - 92R^{-0.1}$	$F_C \times (122 - 104R^{-0.1})$	$F_D \times (156 - 142R^{-0.1})$

The nature of the wind storm also has an effect on the building: cyclonic winds are more demanding of structures than synoptic winds of the same wind speed due to the repetitive nature and duration of cyclonic wind gusts. Sustained cyclic loading during cyclones can lead to fatigue failure of certain elements of a building. During a cyclonic storm a structure will be subjected to numerous gusts at or close to the maximum wind speed while in a synoptic storm, a much smaller number of gusts at or close to the maximum wind speed will be experienced. Thunderstorm downbursts that dominate wind hazard in some regions have very few peak wind gusts associated with them.

The roughness of the terrain upwind of where a building is sited affects the wind speed it experiences, thus a building sited in an open field will be subjected to higher wind speeds than a nearby similar building sited well inside a densely built suburb. The topography around a building will influence the wind speed to which it is subjected, thus a building situated close to the crest of a hill will experience a higher wind speed than a nearby similar building sited on flat ground. In addition, nearby buildings situated immediately upwind of a building in question will tend to shield the building from incident wind, thereby reducing the wind speed to which it is subjected. The magnitude of shielding afforded to a building is dependent on the size, number and spacing of upwind buildings. AS/NZS 1170.2 provides guidance on assessing the effect of terrain, topography and shielding on regional wind speed. Section 2.3 provides further detail on the local effects on regional wind speeds.

In different regions of Australia, strong winds come from certain predominant directions. This can be used to advantage in building design utilising the appropriate factors specified by AS/NZS 1170.2. Table 2 is an extract from AS/NZS 1170.2 showing the wind direction multipliers for the wind loading regions. The directional multiplier is a ratio of the maximum directional wind speed hazard to that for the other cardinal directions (eight directions considered).

**Table 2.** Directional wind multipliers in eight cardinal directions for the A1 to A7 regions depicted in Figure 3 (from Table 3.2 AS/NZS 1170.2, 2002); Tasmania is in Region A3 (highlighted).

CARDINAL DIRECTIONS	REGION A1	REGION A2	REGION A3	REGION A4	REGION A5	REGION A6	REGION A7
N	0.90	0.80	<b>0.85</b>	0.90	1.00	0.85	0.90
NE	0.80	0.80	<b>0.80</b>	0.85	0.85	0.95	0.90
E	0.80	0.80	<b>0.80</b>	0.90	0.80	1.00	0.80
SE	0.80	0.95	<b>0.80</b>	0.90	0.80	0.95	0.90
S	0.85	0.90	<b>0.80</b>	0.95	0.85	0.85	0.90
SW	0.95	0.95	<b>0.85</b>	0.95	0.90	0.95	0.90
W	1.00	1.00	<b>0.90</b>	0.95	1.00	1.00	1.00
NW	0.95	0.95	<b>1.00</b>	0.90	0.95	0.95	1.00
ANY DIRECTION	1.0	1.0	<b>1.0</b>	1.0	1.0	1.0	1.0

In Australia, a simplified methodology for assessing wind forces on houses is specified in *AS 4055-2006 Wind loads for housing*. This standard specifies site wind speed classes for determining design wind speeds (N1 to N6 or C1 to C4). This classification can then be used by other standards (e.g. *AS 1684.2-2006 Residential timber-framed construction*) to prescribe requirements for house framing or other elements. Table 3 shows an extract from AS 4055 showing the wind classes and the corresponding design wind speeds.

**Table 3.** Extract of AS 4055 (2006) *Wind loads for housing*, showing wind classes and their associated design wind speeds (m/s).

WIND CLASS		DESIGN GUST WIND SPEED ( $V_h$ ) m/s AT HEIGHT (10 metres)	
REGIONS A AND B (NON-CYCLONIC)	REGIONS C AND D (CYCLONIC)	SERVICEABILITY LIMIT STATE ( $V_{h,s}$ )	ULTIMATE LIMIT STATE ( $V_{h,u}$ )
N1	–	26	34
N2	–	26	40
N3	C1	32	50
N4	C2	39	61
N5	C3	47	74
N6	C4	55	86

The design wind speeds set out in AS/NZS1170.2 and AS4055, which we are utilising for the initial understanding of wind hazard, are so chosen that a building designed and constructed to resist the wind hazards will have an acceptably small probability of failure over its lifespan. However, legacy buildings that do not comply with the modern standards and older buildings that may have suffered decay over time typically have higher probabilities of failure than modern code compliant buildings. Furthermore, if the wind hazard changes over time, perhaps due to climate change, even houses compliant with current standards may acquire an unacceptably high probability of failure. More simply, this can be expressed as: damage suffered by houses during large storms may become unacceptably large.

The modelled regional and local wind hazard derived from the *Climate Futures for Tasmania* downscaling of six global climate model simulations are discussed in detail in Section 3.

### 2.3. LOCAL WIND HAZARD

The magnitude and impact of severe wind varies considerably between structures at various locations, due to the terrain (surface roughness), the height of the structure concerned, the influence of the surrounding structures and topographic features. Site exposure multipliers can numerically describe the site (local) wind exposure and speed modifications. These multipliers give quantitative measures of local wind conditions relative to the regional wind speed (defined as broad-scale wind speed over open terrain at 10 metre height; see [Section 2.2](#)).

There are three wind multipliers named terrain/height multiplier ( $M_z$ ), shielding multiplier ( $M_s$ ) and topographic (hill-shape) multiplier ( $M_h$ ). The return period gust windspeed for each of eight cardinal directions can be determined using a fourth factor,  $M_d$  ([Table 2](#)). The relationship between the regional gust wind speed ( $V_R$ ) in open terrain at 10 metre height, the maximum local (site) gust wind speed ( $V_{site}$ ) and the local wind multipliers is:

$$V_{site} = V_R \times M_z \times M_s \times M_h \times M_d \quad \text{Equation 1}$$

The types of surface roughness and hill shape are defined in AS/NZS 1170.2. To ensure a safety margin in engineering design, engineers conventionally use design wind speeds, and methods to modify these wind speeds for terrain and topography, that tend to result in larger values than that observed by wind speed measurements. This approach is conservative and prone to estimating design wind speeds higher than the wind hazard (i.e. utilising the wind loading standard as a measure of hazard, in general, provides an inflated intensity for the hazard).

The topographic effect has a profound influence on wind behaviour and hence on local wind speeds and the spatial pattern of wind damage (Walker *et al.*, 1988). Stewart (2003) has developed a simplified probabilistic wind field model to adjust the regional wind speeds to site specific level. A more refined approach was used for a preliminary wind hazard assessment methodology for peak wind gusts based on the Australian wind loading standards for the city of Perth by Lin and Nadimpalli (2005). Thanh and Letchford (2007) compared current US, Australian/New Zealand, European and Japanese wind standards and reported that the treatment of topographic effects in the standards is on the whole conservative.

This study utilises the spatial algorithms developed from the wind multiplier formulae detailed in AS/NZS 1170.2 (2002) and AS/NZS 1170.2 Supp 1 (2002) (as explained in Lin and Nadimpalli, 2005), to estimate the influence of terrain and topography. These algorithms are used to quantify local wind conditions at each location. Across Tasmania, the wind multipliers were evaluated at high spatial resolution (25 metre grid) by applying satellite remote sensing techniques, GIS software and elevation datasets in conjunction with the formula.

Spatial algorithms were developed to estimate the influence of terrain and topography. A significant attempt was made to remove the conservatism associated with the wind loading standard in the spatial approach of wind multipliers. The approach is based on the recommendations of Holmes (2004) to remove the conservatism from the Australian wind loading standard AS/NZS 1170.2 in order to provide an unbiased assessment of hazard. This approach was reviewed by Dr. John Holmes, the Chair of the Australian Standards wind loadings committee (Holmes, 2004).



### 2.3.1 TERRAIN (SURFACE ROUGHNESS) MULTIPLIERS

In order to estimate the terrain/height multiplier and the shielding multiplier, a terrain classification map was developed. Terrain classes from AS/NZS 1170.2 Supp 1 (2002) were used to classify the urban and peri-urban regions considered. Vegetation mapping provided by the Tasmanian Department of Primary Industries, Parks, Water and Environment (DPIPWE) was used to map the terrain of the regions. The satellite remote sensing data has six bands at a 25 metre spatial resolution. The terrain multiplier ( $M_z$ ), as defined in AS/NZS 1170.2, can be calculated for a specified structure using upwind terrain classifications within the specified distance of the structure concerned and the height of the structure. For the hazard determination undertaken, the focus has been on residential structures that typically do not exceed 5 metres in height at the roof level. Local wind hazard for residential structures was assessed using terrain multipliers for a 5 metre height. Table 4 lists the various terrain classes and corresponding terrain categories and roughness factors utilised for this study. A numerical averaging filter was developed for terrain classes upwind of structures of interest, to smooth wind speed changes in from one terrain class to the other.

*Table 4. Terrain/height multipliers used for various terrain classifications*

TERRAIN CLASSIFICATION	TERRAIN CATEGORY	TERRAIN ROUGHNESS	$M_z$ (REGION C)	$M_z$ (REGION A)
CITY BUILDINGS	4.00	2	0.8	0.75
FOREST	3.75	1	0.8	0.77
HIGH DENSITY (INDUSTRIAL) BUILDINGS	3.65	0.8		0.78
SMALL TOWN CENTRES	3.30	0.4		0.81
SUBURBAN/WOODED COUNTRY	3.00	0.2	0.8	0.85
LONG GRASS WITH FEW TREES	2.50	0.06	0.8	0.87
CROPS	2.25	0.04	0.88	0.89
OPEN ROUGH WATER, AIRFIELDS, UNCUT GRASS ETC	2.00	0.02	0.9	0.91
CUT GRASS	1.60	0.008	0.9	0.97

### 2.3.2 SHIELDING MULTIPLIERS

The wind loading standard approach for assessing wind shielding effects was developed primarily for building design applications in which detailed knowledge of the design structure and the building population upwind is available. The methodology for the shielding multiplier ( $M_s$ ) of a structure depends on the number of buildings upwind in a shielding zone which has at least the same height as the structure of interest. The shielding zone is defined as a 45 degree sector with radius of 20 times the building height and centred on the building concerned. A formula is provided in the AS/NZS 1170.2 which utilises the average height, width and number of the buildings affording shielding in the upwind sector. A simplified methodology for the spatial assessment has been developed that provides a coarse treatment of the effects of upwind ground slope on shielding, which in general specifies a smoother wind adjustment relationship. Key steps in the methodology are:

- To apply the detailed AS/NZS 1170.2 provisions to determine typical  $M_s$  values for deep within the range of urban terrains where the corresponding  $M_s$  value was more or less constant. Included were residential suburbs and high rise city buildings. Several locations were trialled using aerial photography to come up with a representative figure (e.g.  $M_s = 0.85$  for residential areas);

- The values were applied to all points on the 25 m grid that are within the suburbs, irrespective of how close they might be to the boundary of the suburb;
- Using a 5 metre nominal building height, a wedge shaped sampling area was developed having the same area as the wind standard defined sector of influence. The wedge area is displayed in Figure 7. The internal angle was widened from 45° to 54° and the hypotenuse reduced to give an equivalent area which encloses the seven data points highlighted in green. A similar wedge was developed for the 45° wind case;
- By moving the upwind wedge area across the 25 m grid average the  $M_s$  values within the wedge obtained a representative shielding value for the location of interest was obtained, marked by a star in Figure 7;
- Shielding value was adjusted for upwind approach slope of the ground using a bi-linear relationship;
- Shielding value was readjusted to remove conservatism (see below).

Finally, the averaged  $M_s$  values were subjected to a spatial smoothing routine to remove outliers, which tends to slightly smear the suburb boundary values. The methodology has provided a smooth transition in  $M_s$  values, when moving from one level of nominal shielding to another, as shown in Figure 7. For a ‘population approach’, in which we are seeking a representative hazard for a large number of homes rather than accuracy for individual structures, we are currently satisfied with this methodology. We have also found this smoothing process necessary for topographical multipliers as well as in the determination of shielding multipliers.

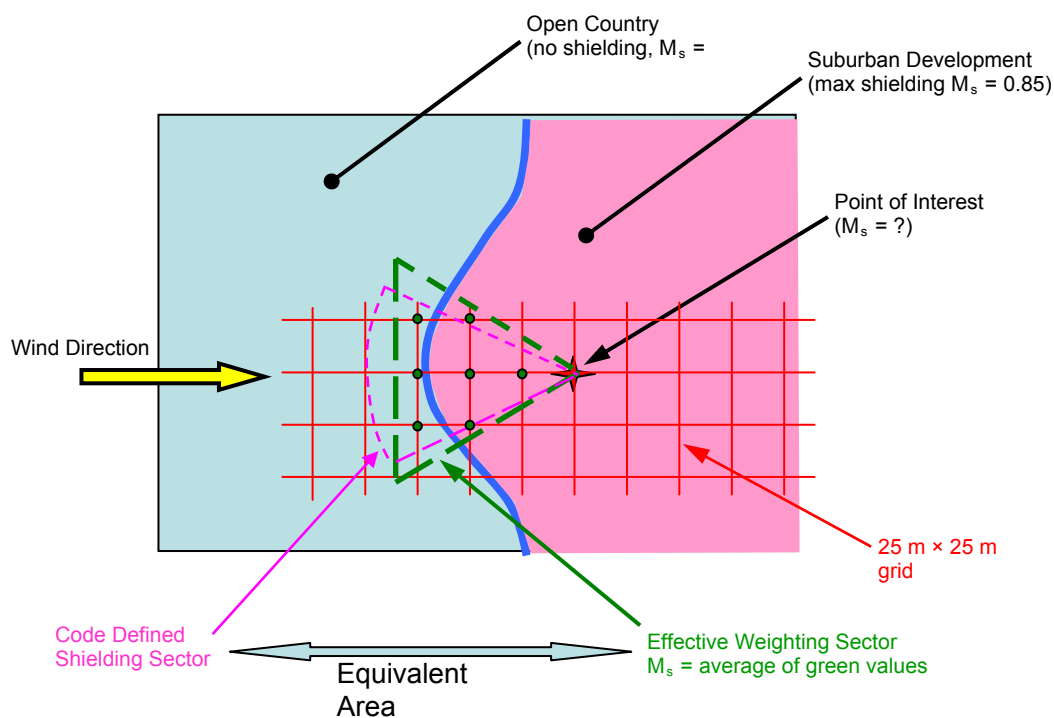


Figure 7. Shielding determination using a sector area equivalent for averaging  $M_s$ .

### 2.3.3 TOPOGRAPHIC MULTIPLIERS

The topographic or “hill-shape” wind effect is caused by the convergence of generally horizontally flowing wind when it meets a hill-slope. Standing on the uphill section of a hill-slope will normally feel windy compared to standing at the base of the slope. In wind engineering it is quantified by the topographic (or hill-shape) multiplier  $M_h$  which applies to a region in the proximity of a hill crest or an escarpment edge called the local topographic zone. It can be estimated using the following formulae taken from AS/NZS 1170.2 (2011):

$$M_h = \begin{cases} 1.0 & \text{for } H/(2L_u) < 0.05 \\ 1 + \left( \frac{H}{3.5(z + L_1)} \right) \left( 1 - \frac{|x|}{L_2} \right) & \text{for } 0.05 \leq H/(2L_u) < 0.45 \text{ or within the local topo zone when } H/(2L_u) > 0.45 \\ 1 + 0.71 \left( 1 - \frac{|x|}{L_2} \right) & \text{for } H/(2L_u) > 0.45 \text{ and within the separation zone} \end{cases}$$

Equation 2.

where

- $H$  — vertical distance from base to crest
- $x$  — horizontal distance upwind or downwind from structure to crest
- $z$  — height of the structure above the local ground level
- $L_u$  — horizontal distance from crest to  $1/2 H$  below crest
- $L_1$  — the greater of  $0.36 L_u$  and  $0.4 H$
- $L_2$  — local topographic zone, to be  $4 \times L_1$  for upwind, and for downwind is also  $4 \times L_1$  for the cases of ridges or  $10 \times L_1$  for escarpments.

A wind “separation zone” located on the leeward side of a ridge or crest is also defined in the standard but is only applicable for slopes greater than 45% in inclination. Equation 2 specifies that slopes below 5% inclination are assigned a  $M_h$  of 1 and that slopes of 45% and above are assigned a  $M_h$  of 1.71 (within the local topographic zone). For the slopes between 5% and 45%, Equation 2 provides the values for  $M_h$  within the local topographic zone.

Table 5 provides  $M_h$  values for a variety of hill slopes. The hill-shape multiplier has a minimum value of 1 but a maximum value of 1.71 when the slope is equal to or greater than 45% (or 24.2 degrees).

**Table 5.** Hill-shape multiplier at crest ( $|x| = 0$ ) &  $z = 0$  (from Table 4.4, AS/NZS 1170.2; 2011).

HILL SLOPE (FRACTION)	HILL SLOPE (ANGLE IN DEGREES)	$M_H$
<0.05	< 2.9	1.0
0.05	2.9	1.08
0.10	5.7	1.16
0.20	11.3	1.32
0.30	16.7	1.48
$\geq 0.45$	$\geq 24.2$	1.71

In the application of Equation 2, the value of  $z$  (height of the structure above the local ground level) is set to zero because of following reasons:

- Estimation of a hill-shape multiplier is required for every grid location within the urban and peri-urban regions being considered, whether the location currently has a building on it or not (i.e. a building height may not currently exist at the location being considered).
- In the case of an existing building, in general the height of the building is unknown without a physical building survey having been conducted.
- $M_h$  values have been found to be relatively insensitive to the value of  $z$ .

The standard provides a 2-dimensional approach for topographic multiplier determination. For the Tasmanian region, the topographic features have been captured by a digital elevation model (DEM) generated from spot height data into a 10 metre grid. Topographic multipliers were generated using the 3-dimensional approach by Windlab Systems for a region containing Hobart and suburban areas including the peri-urban region, whereas the 2-dimensional approach was used for the remainder of the Tasmanian region. The Windlab Systems approach for generating topographic multipliers considering 3-dimensional effects is chiefly used by the wind-power industry for the site-location of wind turbines (for more details see Ayotte *et al.* 2001). The wind accelerations are calculated at heights of 5 and 10 meters using a statistical analogue method for the roughness accelerations and the Raptor model, the fine-scale model within *Windscape* which determines the topographic perturbations (Ayotte and Taylor, 1995).

#### 2.3.4 ADJUSTMENTS FOR CONSERVATISM

The wind loading standard is a building design document that seeks to “envelope” possible wind effects by providing an upper bound rather than an average assessment of local wind hazard. Within the wind engineering community, it is known to be conservative in its approach to shielding by buildings upwind in a “shielding zone”, and also with regard to the topographic shielding of structures.

The beneficial effects of shielding were increased by typically reducing the multiplier by 10%. For open country with a value of  $M_s = 1.0$  no adjustment was made. For  $M_s = 0.9$  or less, we applied a 0.9 factor, as proposed by Holmes (2004), equating to a 10% reduction. For the transition between  $M_s = 1.0$  to 0.9, we applied a linear function to avoid an abrupt drop in  $M_s$ .

Minor modifications were also made to the topographic multiplier ( $M_h$ ):

- For essentially flat terrain (flatter than 1 in 20 or outside the local topographic zone), no adjustment to the multiplier ( $M_h = 1.0$ ) was made;
- For topographic features such as shallow hills and escarpments where  $M_h < 1.4$  a 5% reduction in the multiplier was adopted, and;
- For topographic features such as steep hills and escarpments where  $M_h \geq 1.4$  a 10% reduction in the multiplier was adopted.
- Complex terrain was not considered as a special case.

A review of the adjustments for conservatism, Holmes (2004), affecting the combination of shielding and topographic multipliers indicates that the approach appears reasonable as a representation of the average situation. It should be noted that there is currently no direct experimental evidence (e.g. wind tunnel studies) to support these results.

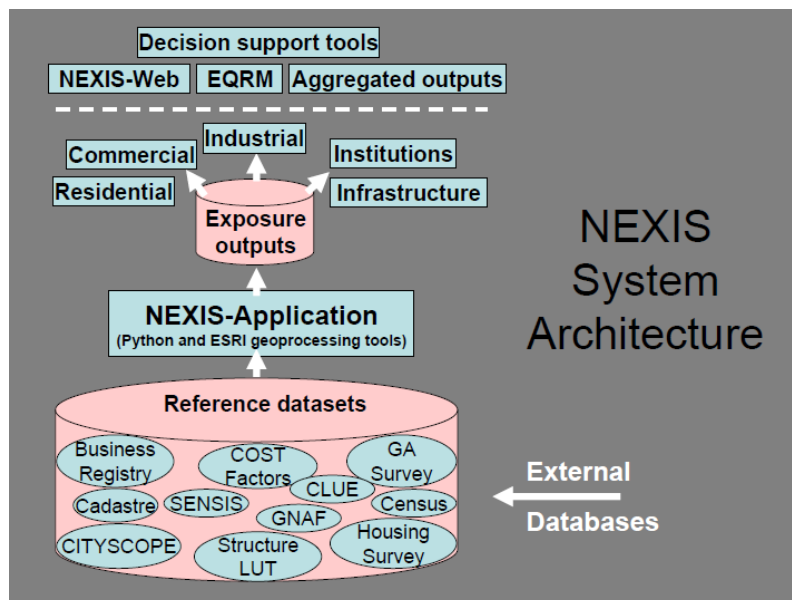
## 2.4. RESIDENTIAL BUILDING EXPOSURE

Exposure information is fundamental in the development of risk-assessment models for natural hazards, critical infrastructure failures and consequences of climate change, and to support early warning systems and national priority initiatives. Building type, construction (roof and wall) type, building age, number of storeys, business type and replacement value (and their spatial location at the building level) are critical parameters for understanding the potential impact on Australian communities from various hazards. In addition to building exposure, the number and type of businesses, critical infrastructure and people exposed are also of interest.

### National EXposure Information System (NEXIS)

The National EXposure Information System (NEXIS) (Nadimpalli *et al.* 2007), which provides a nationally consistent exposure catalogue at the building level for the present time, has also been used to underpin the climate change scenarios for population projections to the end of the century. The development of NEXIS is a project of national significance being undertaken by Geoscience Australia. NEXIS collects, collates, manages and provides the information required to assess multi-hazard impacts. Exposure information may be defined as a suite of information relevant to all those involved in a natural disaster, including the victims, the emergency services, and the policy and planning instrumentalities.

In 2002 the Council of Australian Governments announced that it was committed to establishing “a nationally consistent system of data collection, research and analysis to ensure a sound knowledge base on natural disasters and disaster mitigation” (COAG, 2002). In response to this, in 2004 Geoscience Australia began the development of the National Exposure Information System (NEXIS), which has been significantly accelerated by the need to apply it to climate change applications such as the Garnaut Review (Waters *et al.* 2010). NEXIS has been utilised for a range of vulnerability and risk assessments by Geoscience Australia by integrating it with other modelling systems such as the Earthquake Risk Model (EQR), the national assessment of coastal vulnerability to inundation (a collaboration between Geoscience Australia and the Department of Climate Change and Energy Efficiency), as well as tsunami inundation and risk assessment models.



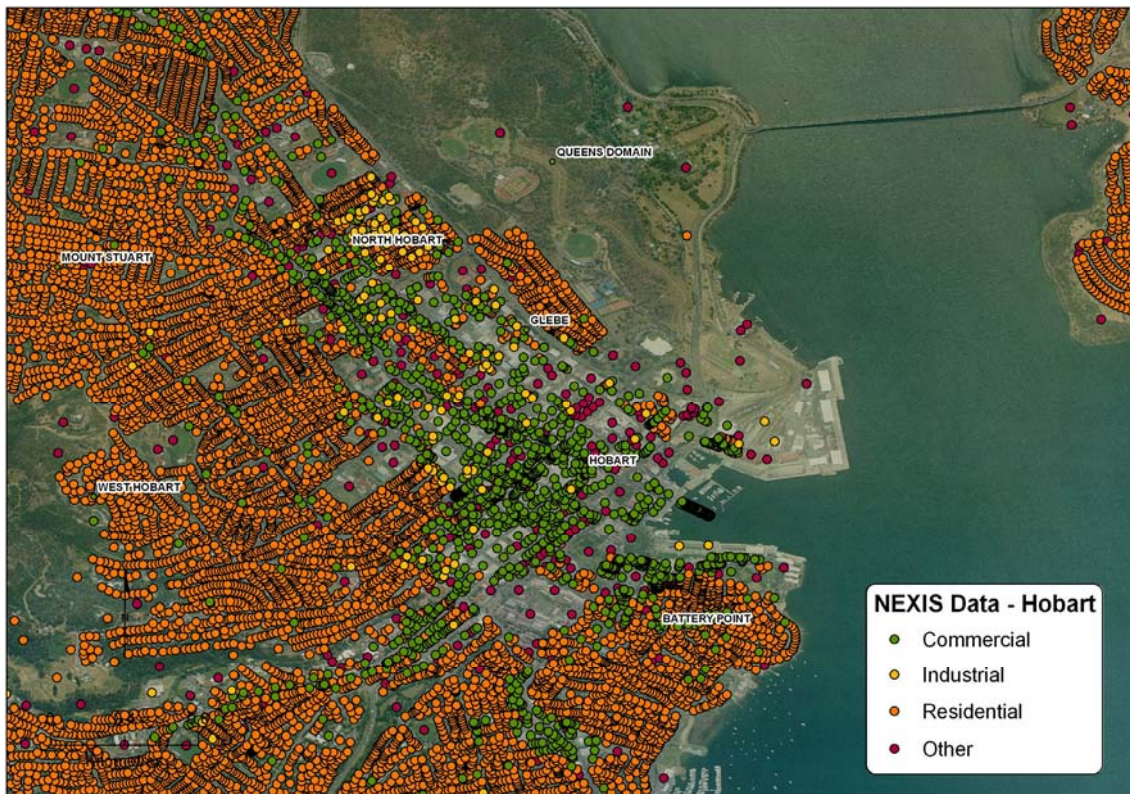
**Figure 8.** NEXIS System Architecture depicting how fundamental datasets are accessed by NEXIS-applications to produce exposure outputs.

Moderating the social and economic impacts of natural hazards and disasters is always a challenge for the various levels of government. A nationally consistent database of exposure is essential for assessing and managing disaster risk, with applications in each of the four phases of *prevention, preparedness, response and recovery* (PPRR). NEXIS has been designed to provide the exposure information that is necessary to carry out national risk assessments. It can supply the comprehensive and nationally consistent exposure information required, derived primarily from reliable and publicly available datasets. [Figure 8](#) shows a graphical interpretation of how the fundamental datasets are accessed by NEXIS-applications to produce exposure outputs. NEXIS maintains information at building level compatible with vulnerability assessment models for multi-hazards – both rapid onset disasters such as earthquakes, tsunamis, tropical cyclones, floods, and bushfires, and slow onset hazards such as sea-level rise due to climate change.

NEXIS information is categorised into residential, business (commercial and industrial), institutions and infrastructure exposure. The information is collated using reasonable and logical assumptions and expressions. Exposure information includes population demographics, income demographics, number and type (construction) of buildings (residential, commercial, industrial and institutions), age of the buildings, type of businesses (4 digit ANZSIC), financial turnover, employees, usage of institutions (education, health, community halls, stadiums etc.) and infrastructure associated with sectors such as transportation (roads, railway, tunnels, bridges, airports, sea ports). [Table 6](#) details the attributes (spatial, structural and economic) available within NEXIS for residential, commercial and industrial exposure. [Figure 9](#) provides an example of the NEXIS classification of buildings for the region surrounding the Hobart CBD.

**Table 6.** Spatial, structural and demographic/economic available within NEXIS for residential, commercial and industrial exposure.

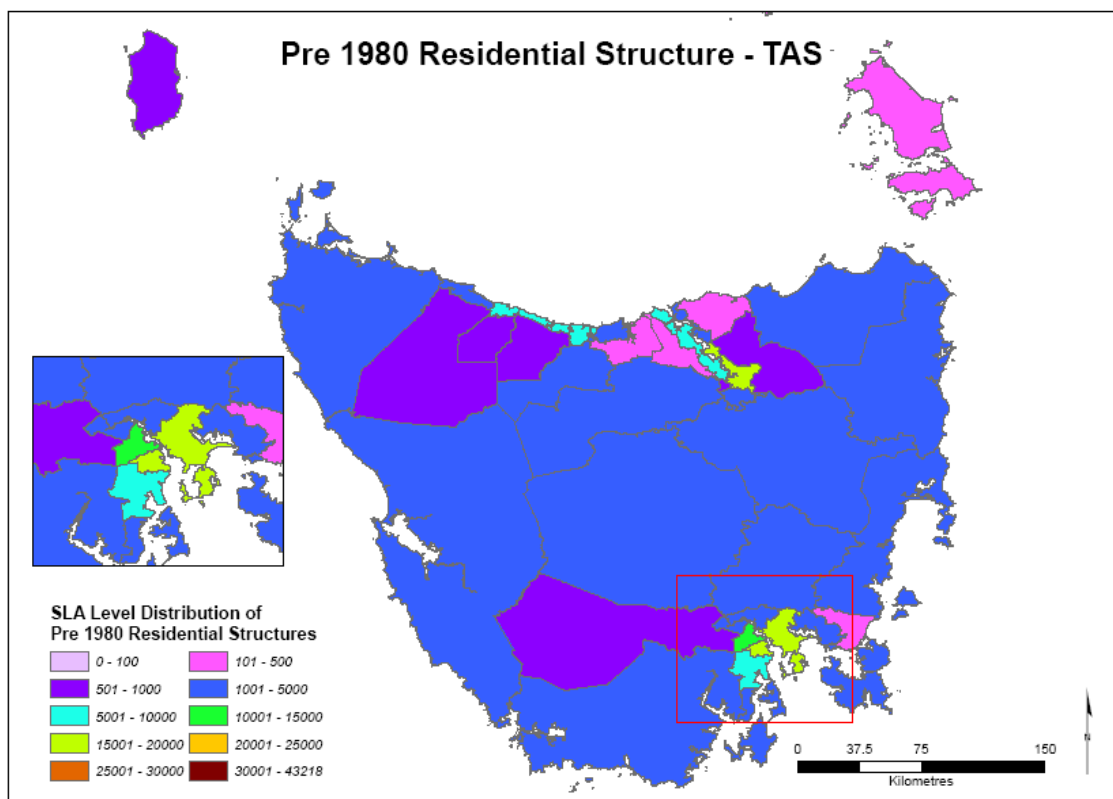
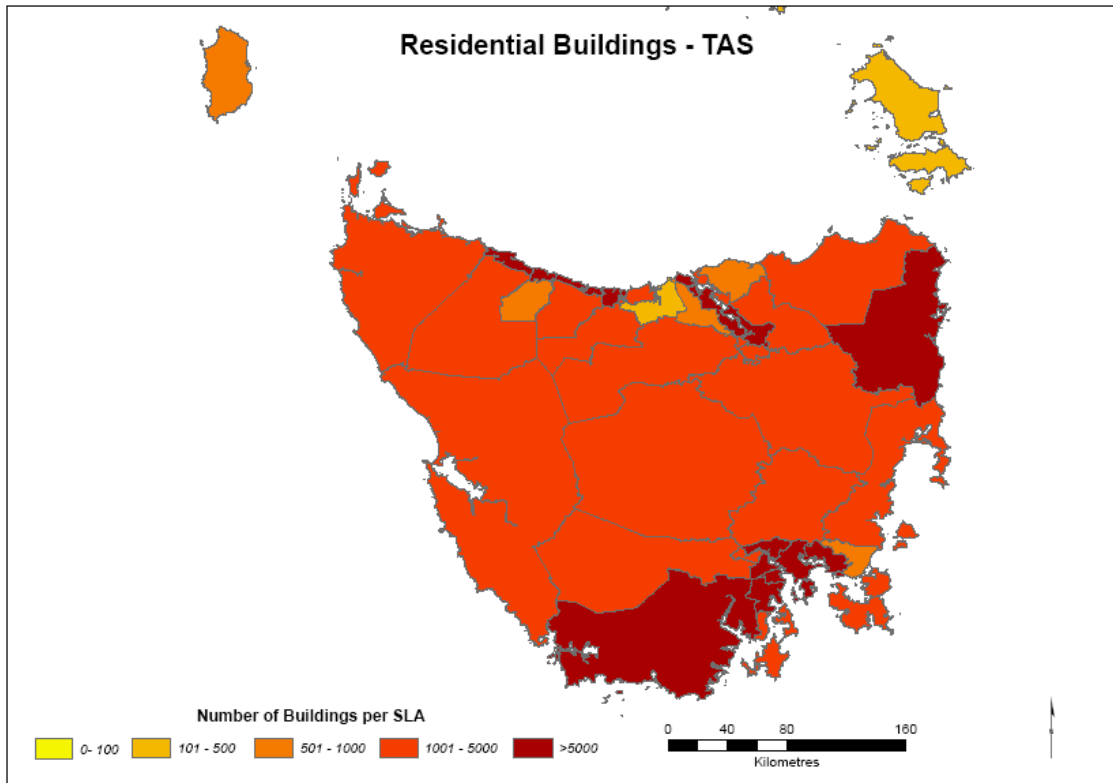
	Residential	Commercial	Industrial
<b>Spatial</b>	Latitude Longitude Address Block size Floor area	Latitude Longitude Address Block size Floor area	Latitude Longitude Address Block size Floor area
<b>Structural</b>	FCB type Roof type Wall type Age	Façade / Wall type Structural system Storeys Basement Car parks Age	Façade / Wall type Structural System Storeys Age
<b>Demographic/ Economic</b>	Income group No. Residences No. People Structural value Content value	Structural value ANZSIC category No. Businesses	Structural value ANZSIC category No. Businesses



**Figure 9.** NEXIS classification of buildings (residential, commercial and industrial) for the Hobart region (surrounding the CBD).

NEXIS was designed to provide nationally consistent exposure information for regional or national impact analyses. In its current form it is not intended to support building level analyses on one or two buildings. Estimating risk at such small scales requires more specific information about the exposure. However, NEXIS is being continually improved, incorporating more specific datasets as they are obtained from data custodians including governments and private data providers.

The generic version of the residential component of NEXIS, containing information built up from assumptions based on sampling the region of interest, is the most utilised for assessing economic impacts of natural hazards on communities and emergency management due to the availability of information at the broad scale and the completeness of the information based on statistical assumptions. The variables required to assess risk for residential areas are primarily spatial, structural and demographic. The spatial location is critical for assessing risk from cyclones, tsunami, flooding and bushfires. National datasets like the ABS Census provide demographic information aggregated at Census District (CD) level, though the risk from natural hazards is not uniformly distributed across the CD. The spatial location is derived from Geo-Coding National Address File (GNAF) and structural details from a small sample of housing survey data. Building age is derived from historical census data sets and the demographic information from the Australian Census (Census 2006).



**Figure 10.** Total number of residential dwellings and number constructed prior to 1980 in each of the 43 statistical local areas (SLA's) in the Tasmanian region.



Figure 10 shows the total number of residential dwellings and number constructed prior to 1980 in each of the 43 statistical local areas (SLA's) in the Tasmanian region. This was obtained from the NEXIS residential exposure catalogue (database). The older structures were built prior to the current building standards and are known to have a higher vulnerability. For this study, NEXIS is used to determine the type, age, location and value of residential buildings “exposed” to the severe wind hazard (enables appropriate vulnerability curve to be employed). NEXIS information on “present-day” exposure was provided at the building-specific level. All values are *replacement costs* are in 2009 Australian dollars. It should be noted that for the analysis of severe wind loss presented in this report, losses are always considered in terms of the percentage of replacement cost.

#### 2.4.1 PROJECTED BUILDING NUMBERS FOR 21<sup>ST</sup> CENTURY

The population projections utilised for this study are provided by the Australian Bureau of Statistics (ABS) and cover the period 30 June 2008 to 2101 for Australia and 30 June 2007 to 2056 for the states, territories, and capital cities/balances of state (ABS 2009). The ABS indicates that these projections are not predictions, but should be considered as having a high probability of covering the range of possible outcomes. They should be utilised to simply illustrate the growth and change in population which would occur if certain assumptions about future levels of fertility, mortality, internal migration and overseas migration were to prevail over the projection period (i.e. is a similar way to the climate projections/scenarios). The assumptions incorporate recent trends which indicate increasing levels of fertility and net overseas migration for Australia. Three main series of projections, Series A, B and C, are utilised. Series B largely reflects current trends in fertility, life expectancy at birth, net overseas migration and net interstate migration, whereas Series A and Series C are based on high and low assumptions for each of these variables respectively.

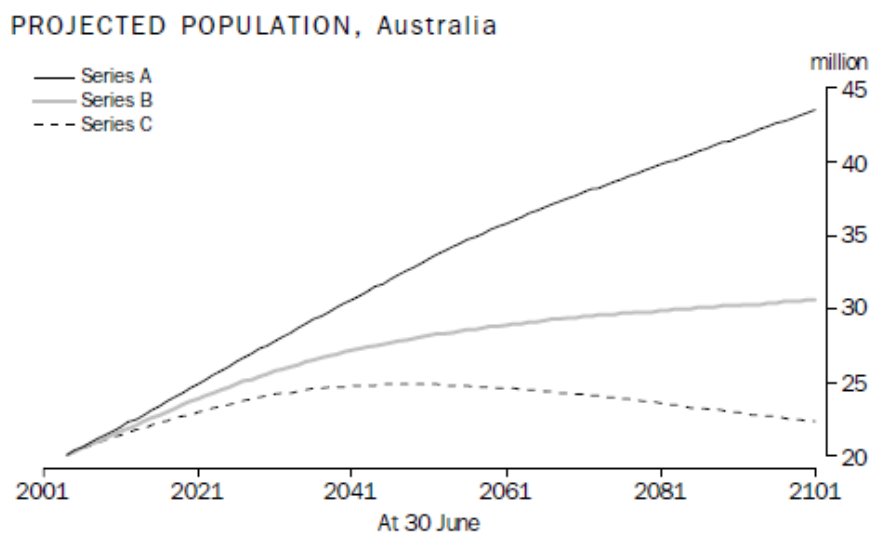
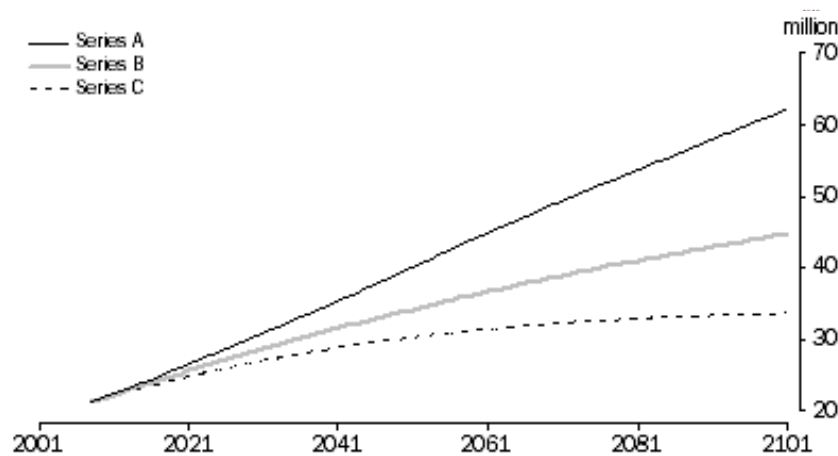


Figure 11. Population of Australia (2007 – 2101) from the Australian Bureau of Statistics Series A, B & C population projections

## PROJECTED POPULATION, Australia



**Figure 12.** Population of Australia (2008 – 2101) from the Australian Bureau of Statistics Series A, B & C population projections

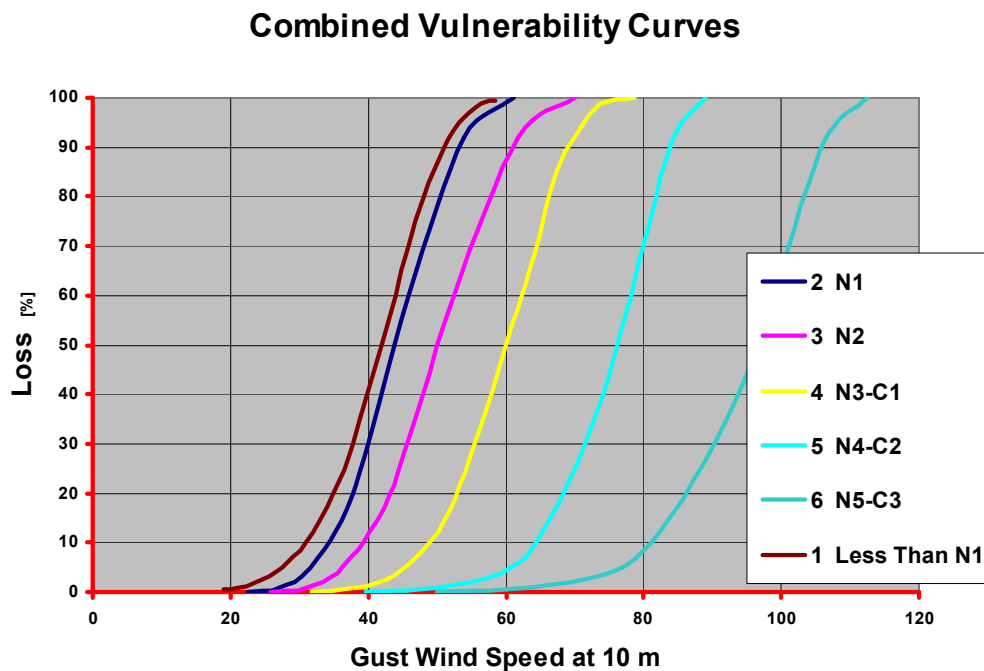
The rate of population growth increases for Series A and decreases for Series B & C. Under these 2006 (Figure 11) projections the total population in Australia is projected to rise from current levels of 21 million to around 44 million by 2100 under *Series A* assumptions, or as low as 23 million under *Series C* assumptions. Since this analysis was conducted, further population projections have been released by the ABS. The new projections take into account the much higher than anticipated levels of Net Overseas Migration experienced in recent years and the increased total fertility rate which resulted in a record number of births over the last 5 years. The population under *Series A* is estimated to grow to 62 million people in 2101, *Series B* to 45 million and *Series C* to 34 million (Figure 12).

As Australia is considered by the rest of the world to be a sparsely populated continent, the combination of global climate change and global population pressures are likely to force successive Australian governments to accept more overseas migration leading to projections at the higher end of the range (Series A) being more likely. Geoscience Australia has used these population projections to illustrate the change in exposure with respect to residential structures. Projections of exposure have maintained the current ratio of people to buildings within each statistical local area (43 regions in Tasmania, see Figure 5). In addition, for the period post-2056, we have maintained the ratio of local to national change in order to maintain the 2056 local trend (for each series) up to the end of the 21<sup>st</sup> century (i.e. only national trend available post-2056). Tasmania is unlikely to grow at the national trend (post-2056) so the 2090 risk estimates are likely to be an overestimate.

## 2.5. WIND VULNERABILITY

Vulnerability relates the capacity of buildings, infrastructure and people to withstand hazards. A significant aspect of this is engineering analysis.

Only direct impact to residential buildings was considered in this study; the wind vulnerability relates the 10-metre height 3-second gust wind speed to the damage level (percentage replacement value in 2009 \$A) for a population of residential structures with identical attributes (i.e. brick veneer walls and tiled roof, constructed post-1980). The vulnerability is normally expressed as an S shaped curve relating *damage index* to the wind hazard. Damage index is defined as the repair or remedial cost divided by the replacement cost for the particular type of building in question. Thus the closer the damage index (DI) is to 1.0 or 100%, the more heavily the building population is damaged. It is important to note that within the building population there will be significant variation in building geometry, construction quality, maintenance and orientation to wind, with each permutation possessing its own vulnerability. Thus a vulnerability curve describes the average vulnerability of the whole population, not individual properties. Figure 13 shows a set of generic vulnerability curves which relate the gust wind speed (at 10m height) to the impact/loss for a population of structures of a certain type and age. The three curves on the right relate to residential structures in tropical regions and high hazard non-tropical regions (see Figure 6 and Table 1). Table 3 provides details for AS 4055 wind classes for N1–N6 and C1–C4.



**Figure 13.** A set of generic vulnerability curves which relate the gust wind speed (at 10 metre height) to the impact/loss for a population of structures of a certain type and age.

Wind damage to houses is strongly related to connection failures and, to a lesser extent, the failure of critical members which do not have sufficient strength to perform their function. That is, under wind loading components often fail by their connections to other components failing (e.g. roofing screws pull out, rafter tie-downs fail and roofs are lifted off), rather than the members themselves failing. Failures are usually tensile failures as wind loads on house roofs are usually upwards, trying to lift the roof off.

The vulnerability of structures is also strongly affected by decay. As a house ages the strength of connections may reduce due to corrosion and rot, thereby leaving the house with an increased

vulnerability over time. Vulnerability also needs to take into account the effects of the nature of hazard. For example, for a structure in a non-cyclonic region (i.e. Brisbane, Gold Coast) subjected to cyclonic winds, the effective strength of connections will be reduced due to the phenomenon of fatigue from sustained and repeated loading. There is also an increased probability of internal pressurisation due to perforation of a building's envelope by flying debris.

### 2.5.1 WIND VULNERABILITY MODELS

There is a paucity of Australian wind vulnerability models for residential buildings, and adopting models published in the international literature could lead to errors as building construction varies around the world. Relationships derived from insurance data by Dr. George Walker of Aon Re for North Queensland structures were in use (Walker, 1995). Walker's pre-1980 curve represents the vulnerability of North Queensland residential structures before the lessons of cyclones Althea (1971) and Tracy (1974) influenced construction practice. His post-1980 curve shows a significantly reduced vulnerability due to changes to the Queensland Building Act. While the curve development process was not a full engineering analysis, these curves were considered the best vulnerability relationships available at the time, and have been used by other researchers (Harper, 1999). Walker's pre-1980 vulnerability curve has been utilised for the residential building populations of Perth, Brisbane and the Gold Coast (Waters *et al.* 2010). Some limited justification for this assignment was derived from a post tornado damage assessment in the Bendigo region (Edwards *et al.* 2004) which showed a correspondence between contemporary brick veneer damage losses and Walker's pre-1980 curve. Residential building types found in Tasmania are similar to those in the Bendigo region, providing some justification for initially utilising the Walker pre- and post-1980 curves to enable a baseline assessment for wind risk in the Tasmanian region. New and more representative wind vulnerability curves were developed in parallel (see next section) and used in this study with the understanding of the attributes which trigger the use of specific wind vulnerability curves (roof type, wall type, age).

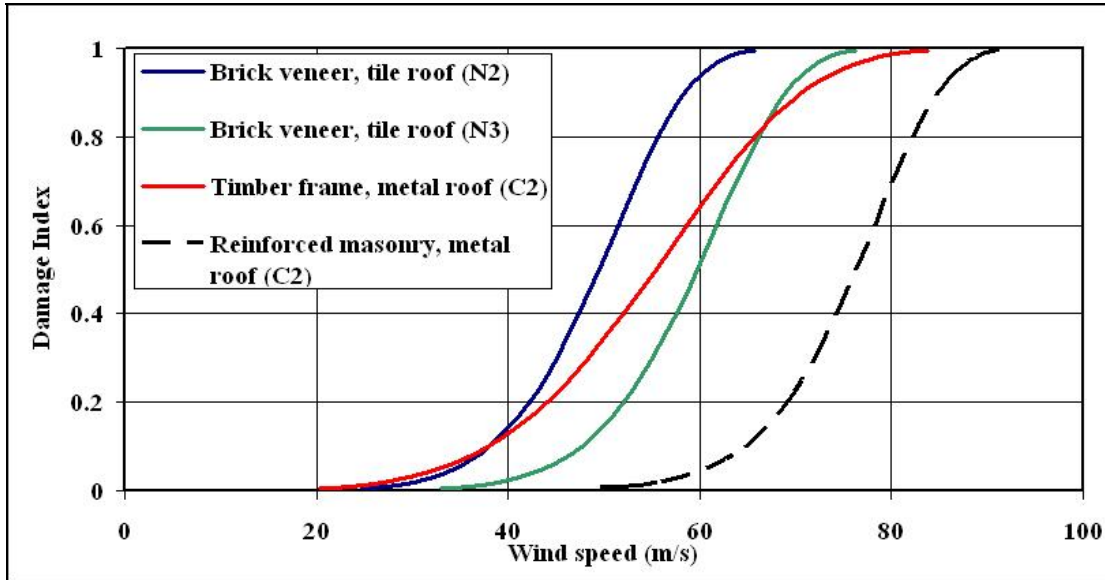
### 2.5.2 DEVELOPING A SET OF HEURISTIC WIND VULNERABILITY MODELS

Heuristic curves that model the vulnerability of the wide variety of residential building types in Australia to severe wind have been developed by Geoscience Australia.

The Australian residential building stock was categorized on the basis of region, age, roof material and wall material. For the modern housing types, a design wind speed was assigned from AS 4055 (2006). This produced a possible 306 categories of which 203 were considered valid categories. The Australian wind engineering community was surveyed to assign heuristic vulnerability curves to the categories of housing, which describe Australian housing by state, region, age, wall construction type and roof construction type. The selection of heuristic curves presented for assignment had been calibrated with some post cyclone damage information (TimberEd Services, 2006). The responses have been averaged to obtain a heuristic vulnerability curve for each category. Mathematical definitions of the curves have been calculated for 203 categories of houses.

The vulnerability of buildings to damage caused by severe wind is normally described by an S shaped curve relating damage index (defined as repair cost / building replacement cost) to the 3 second gust wind speed at 10m height at the building's location. Each building type within the varieties of building that form the Australian residential building stock will respond differently to a severe wind event (gust). In order to be able to estimate damage from severe wind, the range of vulnerabilities covering the building stock types needed to be estimated. Heuristic vulnerability curves that adequately covered the variety of housing that exists nationally were developed through an exercise undertaken by members of the Australian wind engineering community. These wind engineers and wind damage experts assigned vulnerability curves from a standard suite of curves to a detailed categorization of Australian housing types. The heuristic vulnerability curves used for this study are also being used as part of a national study and will be published in a separate report.

Vulnerability curves are often defined by their residential structure *design wind speed category*. [Figure 14](#) shows sample vulnerability relationships for four residential building classes. Each building type is identified by the wall type, roof material and AS4055 site classification.



**Figure 14.** Sample vulnerability relationships for four residential building classes. Each building type is identified by the wall type, roof material and AS4055 site classification. Wind speeds are given in units of metres per second, the damage index has no units.

## 2.6 DAMAGE/LOSS AND ANNUALISED LOSS DETERMINATION

The previous sections discussed the general methodology applied by Geoscience Australia to risk and impact analyses, integrating components of Hazard → Exposure → Vulnerability → Impact/Risk (Figure 3). In this section, we carry out a comprehensive and integrated assessment within this framework. Each element of this paradigm is required to ensure comprehensive and integrated assessment within a consistent framework.

For each return-period hazard level, the potential for residential building damage is linked to the hazard through the vulnerability relationship for the structure type under consideration. Only the direct impact (damage) to residential structures was considered. Damage is calculated through the interaction of wind speed, building exposure and vulnerability. The value of the loss was calculated as the full cost of repair or replacement (“new for old”). This is significantly greater than the insured value where payout is often on a “like for like” basis. The method used to calculate the costs of damage was to assess the return period of exceedance loss levels (50 to 2000 years) at the SLA level across the state of Tasmania. The loss associated with the 10 year return period hazard was considered to be zero for all regions. Losses were then regressed to obtain a Probable Maximum Loss (PML) curve for each SLA and region. The losses represented by the curve range from frequent minor losses through to those associated with catastrophic events having disastrous effects on each SLA region. Annualised loss, which is evaluated by integrating the area under the PML curve (see Figure 3), represents the average annual cost to the region due to exposure to the hazard viewed through a very large length of time (time window of 2000 years was adopted).

## 2.7 HIGH-RESOLUTION CLIMATE MODELING OF THE TASMANIAN REGION

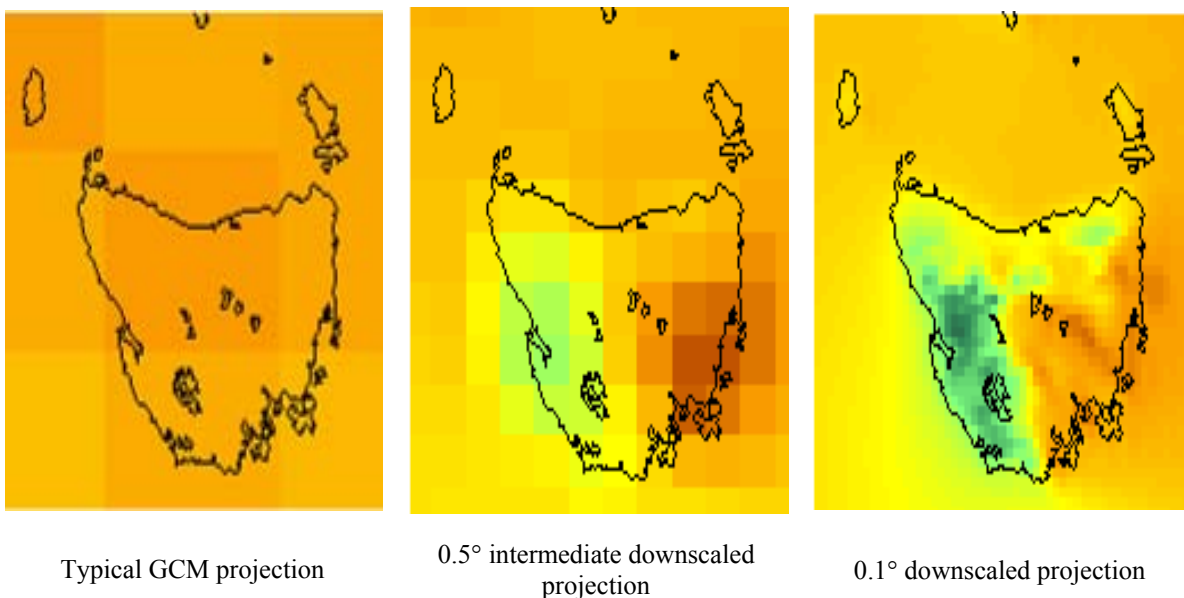
The Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC), Hobart, has produced high-resolution climate change projections for Tasmania as part of the *Climate Futures for Tasmania* project. A key component of the project was to establish possible changes to climatic extreme events as a consequence of climate change up to the end of the 21<sup>st</sup> century. Projections were generated on a 0.1° grid across Tasmania using the CSIRO Conformal Cubic Atmospheric Model (CCAM). Two SRES emission scenarios (Nakicenovic and Swart, 2000) were used to provide a range of likely projected futures, from a low (B1 scenario) to a high (A2 scenario) increase in atmospheric greenhouse gas emissions. In addition, multiple boundary conditions from six general circulation models (GCMs) were used for the period 1961-2100.

Tasmania is an island state which lies between 40° and 43.5° south and has a varied temperate maritime climate. The island is mountainous in the western, central and north-eastern and southern parts of the state, affecting the flow of air overland and the spatial distribution of extreme wind events. The Tamar valley (runs north-west from Launceston to the coast either side of the Tamar River) and the Derwent valley (south central Tasmania) are affected by a maritime climate and are where the main settlements are located. The principle characteristic of the Tasmanian climate is the interaction between prevailing westerly winds and the mountain ranges near the west coast and the central plateau. GCMs are typically of relative coarse resolution and do not have the necessary skill to capture Tasmania’s varied topography and climate (e.g. land-sea interactions) accurately. A regional downscaling approach was employed to model the spatial variability of the state’s climate (Corney *et al.*, 2010). Six GCMs were dynamically-downscaled using the CCAM model (McGregor, 2005; McGregor and Dix 2008) at a grid resolution of 0.1° degrees for the period 1961-2100. The GCMs selected are detailed in Table 7. The model selection was based on an assessment by Smith and Chandler (2009) that examined the ability of selected models at reproducing the present-day climate of the Australian region.

**Table 7.** Parent model (driver) for the CCAM climate simulations (regional downscaling)

CCAM “parent model” (driver)	Institution	Abbreviation
CSIRO mark 3.5	CSIRO (Australia)	Mk3.5
ECHAM 5	Max-Planck Institut (Germany)	ECHAM5
GFDL CM 2.0	Princeton Univ. /NOAA (USA)	GFDL2.0
GFDL CM 2.1	Princeton Univ./NOAA (USA)	GFDL2.1
MIROC 3.2 medres	Interdisciplinary Research on Climate (Japan)	MIROC3
UK Hadley CM3	Hadley Centre Met Office (UK)	UKhad

The CCAM dynamical downscaling process (Katzfey et al., 2009) uses a stretched-grid global model with forcing data taken from a host GCM. The result is a fine-scale grid of information over the area of interest (dynamically downscaled region). A two stage downscaling process was required to achieve the final resolution of 0.1°. The first stage (intermediate model) involved downscaling from the host GCM to a grid with the high-resolution face of the cubic conformal grid covering all of Australia at a resolution of approximately 0.5°. The second stage placed the high-resolution face over Tasmania and the Bass Strait islands at an approximate resolution of 0.1°. **Figure 15** shows the average annual precipitation totals for Tasmania at the three grid resolutions (a typical GCM and the two stages of downscaled results; demonstrated by GFDL-CM2.1 model). A typical GCM resolution (left panel) only has two or three grid cells covering the state. The 0.5° resolution model (centre panel) shows an improved spatial pattern of precipitation, with the predominantly dryer eastern and wetter western regions starting to be defined. The finest 0.1° resolution model (right panel) closely resembling the observed spatial pattern of annual precipitation. It was concluded that the high-resolution 0.1° dynamical downscaling process had the ability to model the local climate of Tasmania accurately across the downscaled models, including seasonality, spatial variance and relationships between the different climate variables (Corney *et al.*, 2010).



**Figure 15.** Average annual precipitation totals for Tasmania projected on typical GCM, 0.5° and 0.1° grids (Corney *et al.*, 2010). Precipitation scaled from 0-3000 mm per annum.

## 3. Modelled Wind Hazard

Regional dynamically-downscaled general circulation models (GCMs) were employed to investigate current and future extreme wind events, in particular their spatial characteristics over the Tasmanian region and changes in intensity over the 21<sup>st</sup> century. Current climate hindcast model outputs (1961-1990) of wind extremes were also compared with observations. A bias-adjustment procedure was employed to spatially correct wind extreme magnitudes utilising observations from Wynyard, Launceston and Hobart. Events were fitted to a Generalised Pareto Distribution (GPD) using an automated threshold selection procedure developed for gridded extreme wind datasets. Return-period (RP) estimates of wind gust extremes were calculated using extreme value analysis. In addition, we also used the wind loading standard (AS/NZS 1170.2) as a proxy for hazard, functioning as an additional benchmark to validate our current climate hazard against.

### 3.1 REGIONAL WIND HAZARD

It is essential to have a good understanding of the actual level of severe wind hazard across the country to assess the impacts on Australian communities. One of the fundamental components of wind risk is an understanding of the wind hazard.

Geoscience Australia has used new statistical models to develop a spatially-specific understanding of wind hazard arising from synoptic storms and thunderstorm downbursts. We do not address wind hazard from tornadoes, as these are very rare events and, as such, there are insufficient observations to develop robust statistical models of their occurrence. The other significant cause of severe wind damage, east coast lows, are not addressed explicitly but are incorporated into the synoptic wind hazard. There are two key purposes for developing new techniques to evaluate wind hazard:

- Provide an improved spatial representation of wind hazard;
- Allow application of the techniques to climate model data.

The former permits an improved spatial understanding of wind hazard at any point, rather than being restricted to the relatively few wind observation points, which are usually on open plains at airports. The latter permits an analysis of the impact climate change will have on wind hazard and risk in the future. By deriving a baseline estimate of wind hazard from climate model data, it follows logically to apply the same technique to projected climate model data. We consider wind gusts associated with synoptic winds (mid-latitude weather systems) as the climate model only provides hourly mean wind speeds (model maximum time-step value each hour) at a resolution of 14 km, which does not resolve thunderstorms and tornado events. For thunderstorm gust winds, we employ a technique where the environment conducive to thunderstorm occurrence/development is examined. In considering climate change, two IPCC scenarios are utilised: scenario B1, a low emissions scenario, and scenario A2, a high emissions scenario (Nakicenovic and Swart, 2000). Both current and future climate are considered utilising the model output data described in [Section 2.7](#).

The hazard modelling methodology utilised here follows the technique proposed by Holmes and Moriarty (1999) which suggests that wind hazard from thunderstorm downbursts and synoptic storms to be evaluated separately. The mechanisms that cause these extreme events are very different, and their impact footprint (spatial scale of damage) varies greatly between these two types of events. Thunderstorm damage in general tends to be very localised and severe whereas synoptic storms tend to cause widespread damage where, on average, the level of damage is generally lesser in magnitude.

### 3.2 MODELLED REGIONAL WIND HAZARD – SEVERE SYNOPTIC WINDS

The term synoptic storm refers to all weather events experienced in the Tasmanian region which are associated with large-scale meteorological systems and excludes thunderstorms and tornadoes.



Synoptic storms can range from east coast lows to Southern Ocean polar lows associated with cold fronts that sweep over Tasmania, with one storm capable of impacting settlements 100's of kilometres apart. These intense low pressure systems can cause significant losses across the state. The existing understanding of wind hazard in AS/NZS 1170.2 (2011) Region A is based on observed wind speeds at a limited number of observing stations around Australia and New Zealand, which includes observations from two sites in Tasmania (Hobart and Launceston).

The synoptic wind hazard model involves three computational processes:

- Calculation of return period (RP) for gust wind speed using a statistical model;
- Extraction of wind speeds from a high resolution climate model; and
- A Monte Carlo method to generate synthetic gust speeds based on a numerical convolution of modelled mean speeds and an empirical gust factor.

### ***Statistical model of severe synoptic winds***

The core of the statistical model is the fitting of Extreme Value (EV) distributions to a dataset of wind speeds. EV distributions allow us to make inferences about the magnitude and frequency of extreme events beyond the range of years available in the observed record (Coles, 2001). Wind hazard is quantified by calculating *return periods*. The model uses the Generalised Pareto Distribution (GPD) to calculate the return period of maximum daily wind speeds, employing an automatic algorithm to find the appropriate threshold to fit the GDP to datasets (Sanabria and Cechet, 2007).

The modelling of synoptic wind hazard makes up one part of the statistical model of severe wind hazard developed for non-cyclonic areas of Australia, described in Sanabria and Cechet (2007). The model uses maximum daily gust wind speeds recorded at BoM weather stations across Australia. Those records that can be attributed to thunderstorms and/or tropical cyclones are excluded, as these phenomena are examined separately. The synoptic wind hazard model uses the 'peaks over threshold' method to fit the parameters  $\sigma$  and  $\xi$  to an extreme value distribution, most commonly the Generalised Pareto Distribution (GPD), which is preferred when daily maxima of the observed variable are available (Holmes and Moriarty 1999). The major limitation of the GPD in practical work is the selection of the appropriate threshold  $u$  for the given dataset. Values above the threshold are considered for fitting the GPD and for this reason the GPD is very sensitive to the threshold selection (Sanabria and Cechet 2007). A discussion on the automatic selection of the threshold is given in Sanabria and Cechet (2007). The exceedance values of the GPD for a given return period  $t$  are defined as:

$$w(t; u, \zeta, \sigma, \xi) = u + \frac{\sigma}{\xi} \left[ (nt\zeta)^\xi - 1 \right] \quad \text{Equation 3}$$

where  $u$  is the threshold,  $n$  is the number of observations per year (in this case 365) and  $\zeta = \Pr(w > u)$  is the probability of the wind speed  $w$  exceeding the threshold  $u$ .

Statistical models for wind hazard assessment have a number of limitations; in particular these types of models are very sensitive to the quality of the data records. Wind records can be affected by anemometer shielding (growth of nearby trees, new housing developments), anemometer position and instrument changes (recalibration or replacement), as well as changes in the observing frequency (e.g. from minute to 3-hourly) and the change to digital/automatic recording instead of manually scaling paper records. Furthermore, instruments are calibrated for mean wind speed, and their transient response to short wind gusts is not always determined. Additionally, not all stations record gusts, which is the key variable in wind hazard assessment for the Australian region; in UK/Europe they use mean hourly winds and scale this information. For these reasons a simulation model based on synthetic data rather than observations was developed (Sanabria and Cechet 2010). The model carries out a Monte Carlo simulation of the physics of gust wind generation for synoptic wind events.

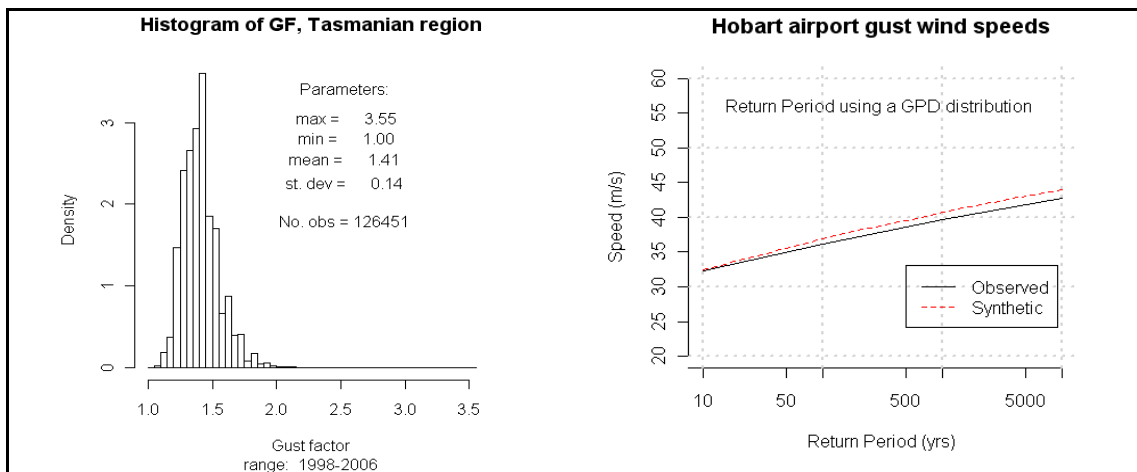
**Monte Carlo (MC) generation of wind gusts**

The MC works by simulating the physics of wind generation for synoptic wind conditions. It assumes that surface wind gusts result from the deflection of air parcels flowing higher in the boundary layer which are brought down by turbulent eddies (Brasseur 2001). The method separately takes into account the mean wind and the turbulent structure of the atmosphere. Turbulence is represented by the gust factor. The process consists of the numerical convolution of the mean wind speed and the gust factor to produce gust wind speeds (Sanabria and Cechet, 2010).

The implementation of the MC process in gridded data involves three steps:

- Calculation of a representative (observed) regional gust factor;
- Extraction of mean wind speeds in each cell of the grid; and
- Calculation of corresponding gust wind speeds by MC simulation.

The gust factor (GF) is defined as the ratio of maximum wind speed (*gust*) and mean wind speed for the same time period (generally between one and ten minutes duration). For this study the GF was calculated from the half-hourly wind speed datasets provided by the Bureau of Meteorology (BoM).



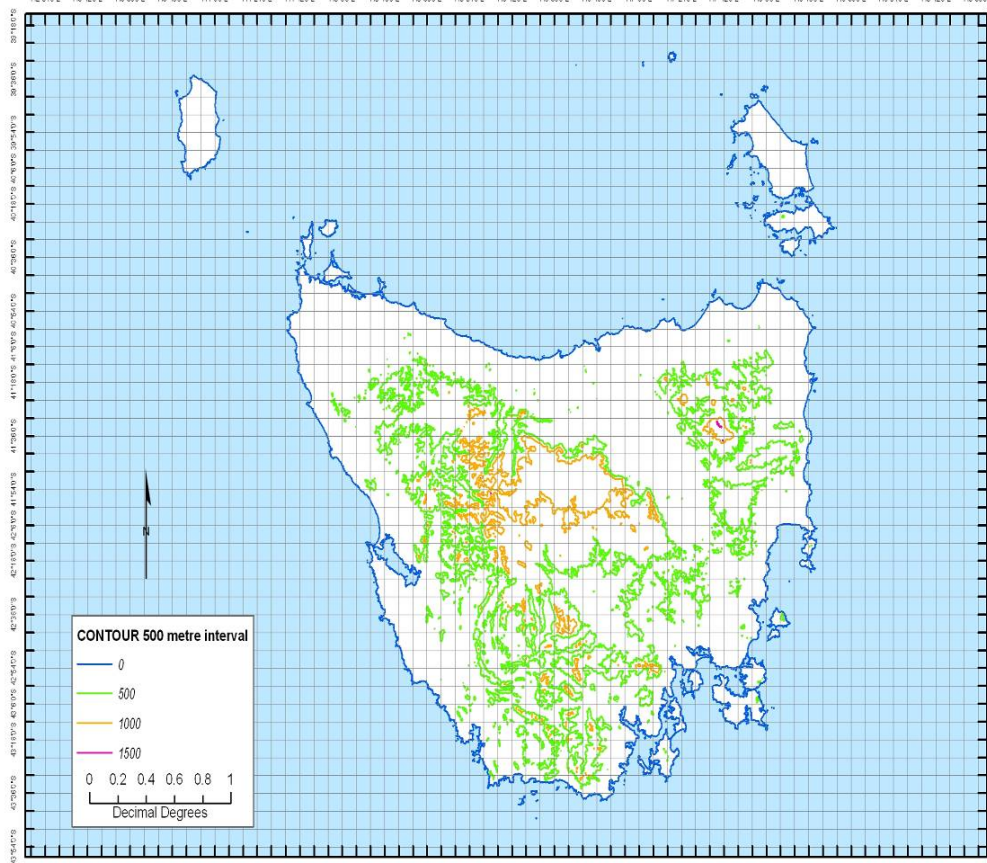
**Figure 16.** Gust factor (left) and return period of gust wind speed (right) using Monte-Carlo simulation for Tasmanian region and Hobart Airport. The synthetic dataset contains a significantly greater number of extreme values (based on data from Hobart, Launceston and Wynyard airports) which better define the extreme upper tail of the distribution.

In order to capture the regional characteristics of Tasmania, wind speed data for three Tasmanian stations were acquired from BoM. These sites were selected because their weather observing stations and anemometer measurements are located at airports, avoiding the problem of the urban environment or trees affecting the instruments, and also due to these stations having gust wind speed records. The three datasets were joined into a single super-station in order to calculate a *regional* GF which was applied to all of Tasmania (see Figure 16). This GF was used for the sampling process in the Monte Carlo simulation. To avoid the generation of very large gust speeds due to the long tail of the GF distribution, this distribution was ‘shaved’ at the 85th percentile, i.e. only values of the GF distribution less than or equal to the 85th percentile were used. This eliminates short duration, high intensity events from the dataset, which are not associated with synoptic winds (i.e. these are either associated with thunderstorms or assumed to be associated with thunderstorms).

**Current-climate wind hazard**

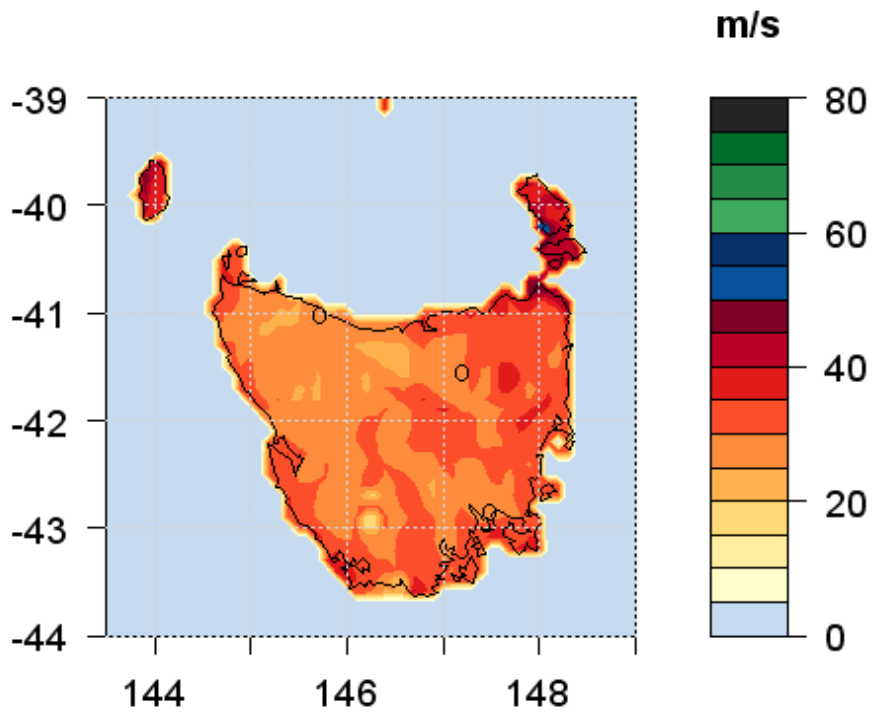
The methodology was applied to the gridded data over the Tasmanian region to obtain return periods (RPs) of gust wind speeds. For each grid cell, mean wind speeds were extracted from the CCAM simulations forced by the NCEP/NCAR reanalysis for the period 1961 to 1990. Then representative *gust* wind speeds in each cell were generated using the MC process outlined above. Finally, from these gust speeds, RP for 50 to 2000 years were calculated using the statistical model.

To correct the bias which exists when comparing area-averaged climate simulated and location-based wind speeds, the RP of observed gust wind speeds at the three selected stations were generated and a bias correction factor (ratio of observed RP and CCAM-generated RP of current climate) was calculated to force the CCAM-generated RP of gust winds at the selected stations to be similar to the observed; this correction factor was applied to all cells in the grid.

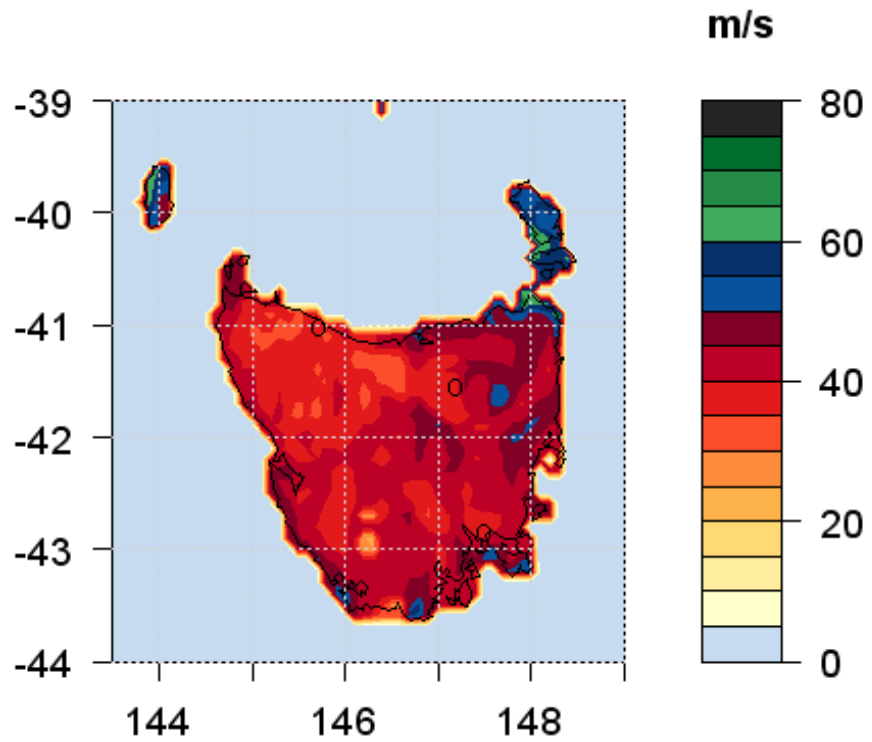


**Figure 17.** Contour map of Tasmanian elevation.

Figure 17 shows the contour map of the elevation over the Tasmanian region. Figure 18 shows the six- GCM model average 500-yr RP mean wind speeds in m/s (current climate). As expected, synoptic winds follow closely the texture of Tasmanian topography, in particular note the increase of synoptic wind speeds due to the effect of the mountain slope in both the west and the north-east parts of Tasmania. This is consistent with detailed studies of the effect of mountain slopes on wind speeds (Holmes, 2007). Figure 19 shows the corresponding 500-yr RP of gust wind speeds generated by MC simulation (current climate).



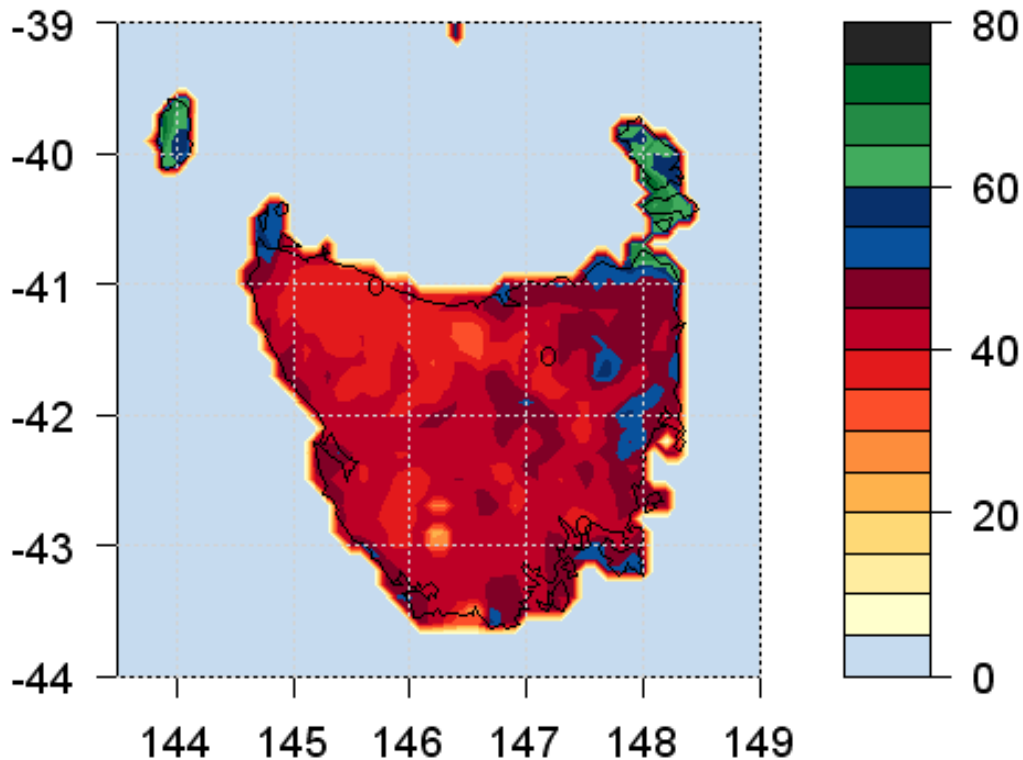
*Figure 18. 500-yr return-period (RP) of modelled mean wind speeds (current climate) at 10 metre height over coarse resolution topography/terrain (at 14 km horizontal resolution).*



*Figure 19. 500-yr return-period (RP) of modelled gust wind speeds (current climate) at 10 metre height over coarse resolution topography/terrain (at 14 km horizontal resolution).*

**Future climate synoptic wind hazard**

Synoptic wind hazard under future climate was determined by considering 20 year windows centred on the decadal time-period of interest (2050 and 2090 for the B1 and A2 climate change scenarios are shown here; each utilising a six member GCM ensemble). The 500-yr return-period (RP) of gust wind speed for 2050 (A2 scenario) is shown in Figure 20 (six-model ensemble average). Significant increases in wind hazard in the mountainous north-east region and also Flinders and King Island is observed for 2050.



**Figure 20.** 500-yr return-period (RP) of gust wind speed for 2050 (A2 scenario) at 10 metre height over coarse resolution topography/terrain (at 14 km horizontal resolution).

Figure 21 shows the change in wind hazard (percentage) of scenario A2 with respect to scenario B1 for 2050 using the six-model average 500-yr RP as the baseline. There are small increases in the regions of high hazard (east and north-west), and there is a decrease in wind hazard in the central regions when scenario A2 is considered. In general the difference between scenarios B1 and A2 for this case represents no more than 15%. Figure 22 shows the corresponding difference between scenarios B1 and A2 for 2090.

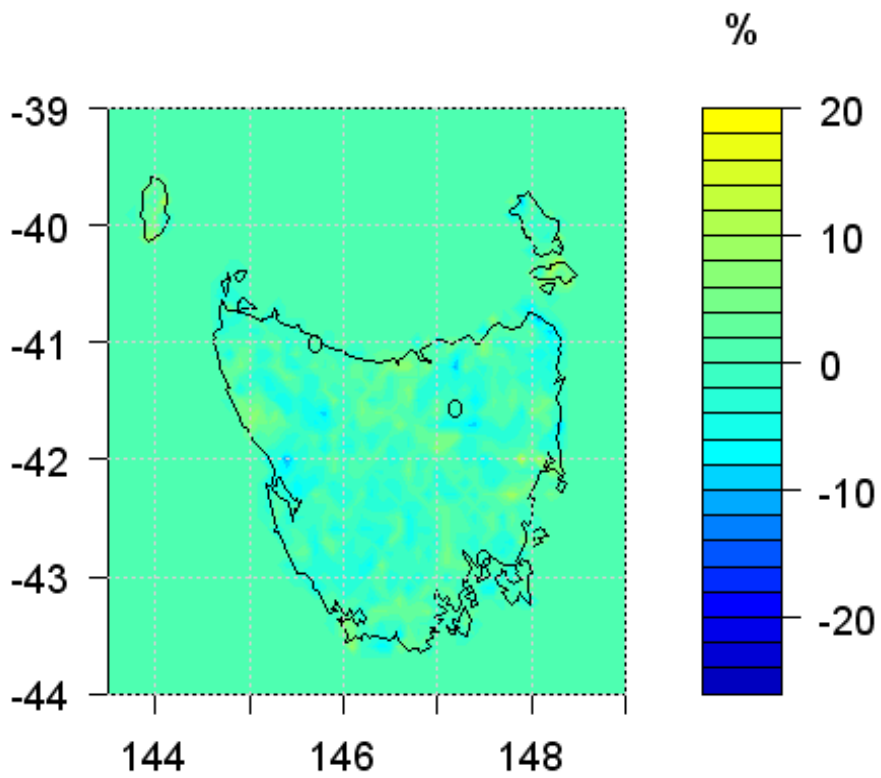


Figure 21. Wind hazard percentage change (%) of A2 scenario with respect to B1 scenario (2050).

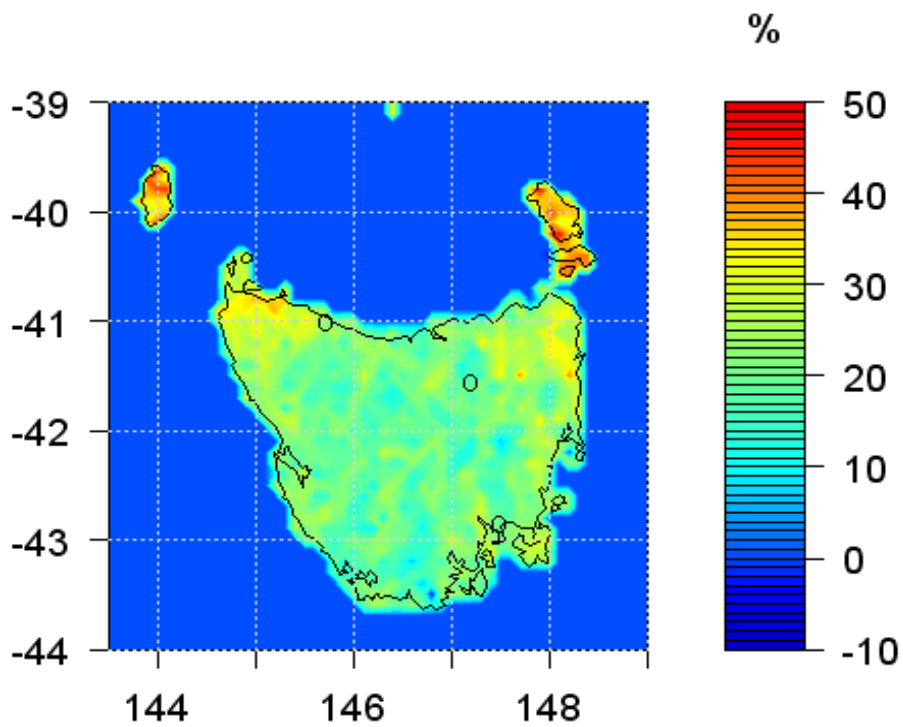


Figure 22. Wind hazard: percentage change (%) for A2 scenario with respect to B1 scenario (2090).

By 2090 a greater difference in hazard between the two climate change scenarios is observed. In the north-east and north-west of the state, the regions of higher wind hazard, an increase of up to 45% can be observed. There is a very small increase in wind hazard in the south and central part of Tasmania when using scenario A2 instead of B1.

It is also important to assess the increase of wind hazard in future climate with respect to current climate. Results for the higher greenhouse gas emissions scenario (A2) are shown in Figure 23 which depicts the percentage difference in wind hazard for 2090 when compared with current climate. An increase in wind hazard by 2090 in the regions of high hazard (north-east and north-west) and a reduction in the south and central areas can be observed. Figures 22 and 23 show a similar trend, the difference in percentage between scenarios A2 and B1 is similar to the difference between 2050 and current climate for the A2 scenario.

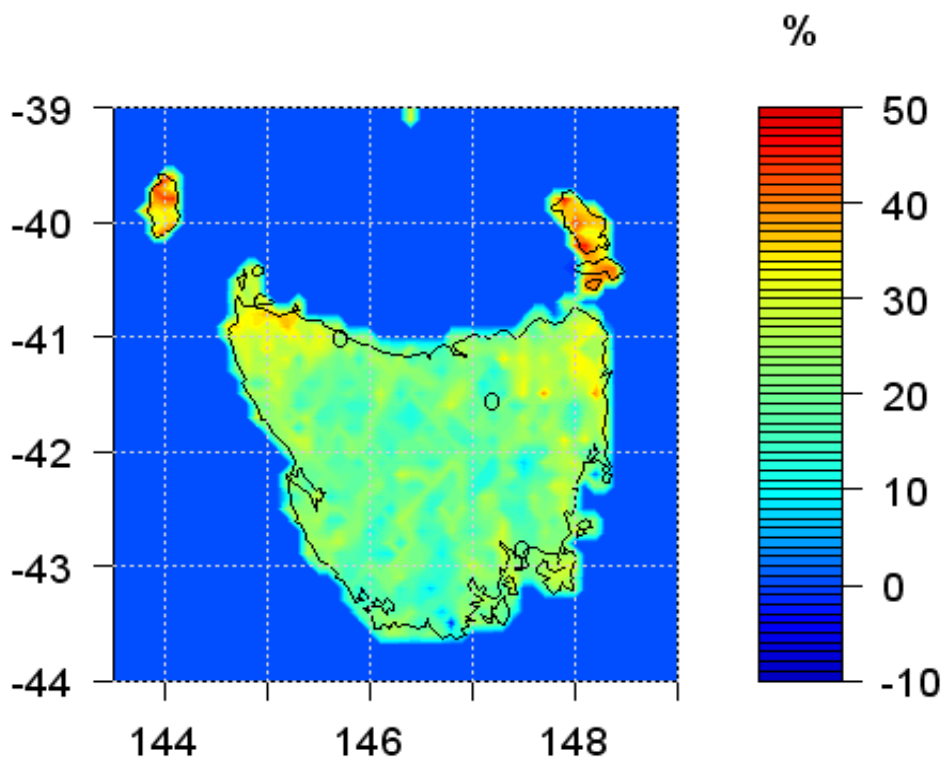
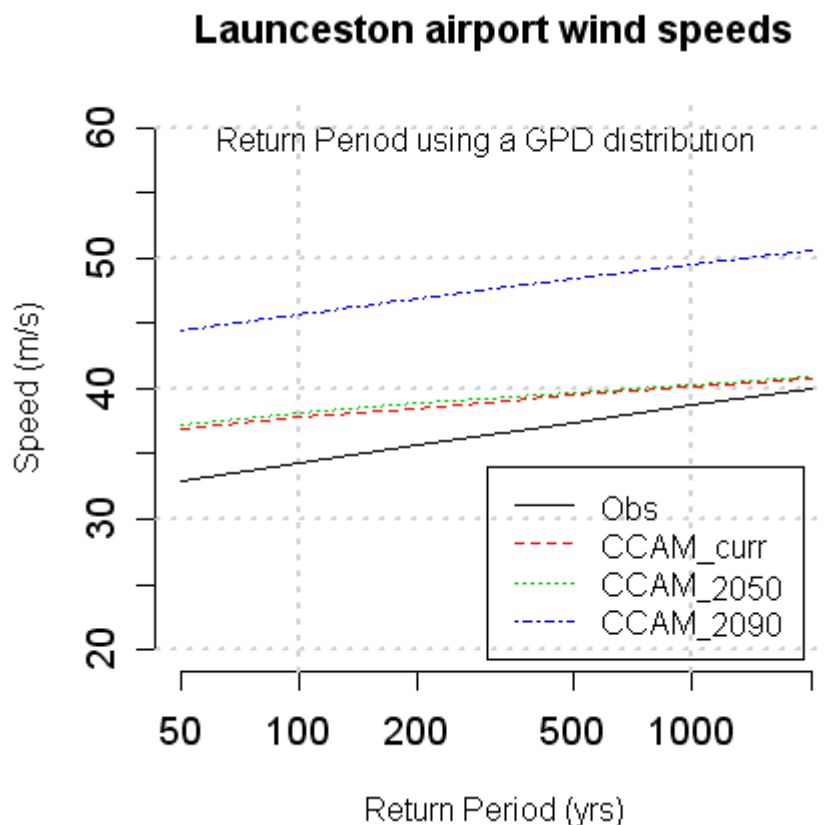


Figure 23. Wind hazard percentage increase of A2 scenario for 2090 with respect to current climate.

To observe the change in wind hazard at a given location, the RP of observed and CCAM-modelled wind hazard at the Launceston Airport observing station is presented. The six-model ensemble average RP of gust wind speeds for a wide range of years (50-2000 years) was calculated by averaging the gust wind speeds at a given RP for each of the models. Figure 24 shows the RP curves for observed wind speeds and also for three CCAM-modelled time-windows: current climate, 2050 and 2090. The CCAM-modelled RP of gust speeds for current climate are higher than those observed especially at low RP. For wind hazard we are more interested in the high values of RP and for Launceston Airport they tend to be closer to the observed values. The trend for wind hazard during the 21<sup>st</sup> century (A2 scenario) for the model ensemble average is also shown; RP for 2050 are very similar to RP for current climate; whilst for 2090 there is a substantial increase in wind hazard.



**Figure 24.** Return-period (RP) hazard at Launceston Airport for 2050 and 2090 (CCAM downscaled output; A2 scenario).

**Long-term trend in wind hazard**

To assess the long-term trend of gust wind hazard in Tasmania, we examined the 500-year RP of gust wind speeds for eight 20-yr time windows (A2 scenario) for three selected stations. The RP values from each simulation have been standardised with respect to the current climate by using the expression:

$$RP_{standard} = (RP_{mod_j\_time\_slice_k}) / RP_{mod_j\_curr}$$

where:  $RP_{mod_j\_curr}$  = Gust wind speed RP of current climate from model “j”  
 $RP_{mod_j\_time\_slice_k}$  = Gust wind speed RP of model “j” at time slice “k”

Figure 25 presents the standardized 500-year RP values (“stand. RP”) for Launceston Airport, A2 scenario (the x-axis is the mid point of the time window). Note that the first point corresponds to current climate. We observe that most model results are located above the “1.0” line, i.e. all models project an increase in wind hazard with respect to current climate. There are however large differences in the level of increase and in the time window they happen. GFDL21 for instance projects an increase of 30% by 2040 and MIROC projects a decrease of 15% by 2020 (i.e. using the data between 2010 and 2030) which provides some indication of the extent of interdecadal variability indicating the need for either a multi-simulation (single model) or ensemble of models approach (as undertaken). The black lines show the ensemble mean-value at each x-axis point and the dashed line shows the ensemble average over the total time-series. The former is the mean value of the six-model RPs calculated at each time window and is shown with the full line, the latter is shown using a dashed line and it is the linear regression (LR) calculated from all RP values in the plot. The LR line shows that the long term trend in this station is for a very small decrease in wind hazard. The corresponding plots for the Hobart Airport station, A2 and B1 scenarios are presented in



Figures 26 and 27. The Hobart Airport observing station shows a similar trend in terms of individual models; again a large variation is observed. Note however that the long-term trend for synoptic wind hazard at this station is for a small increase in the hazard (dashed black line).

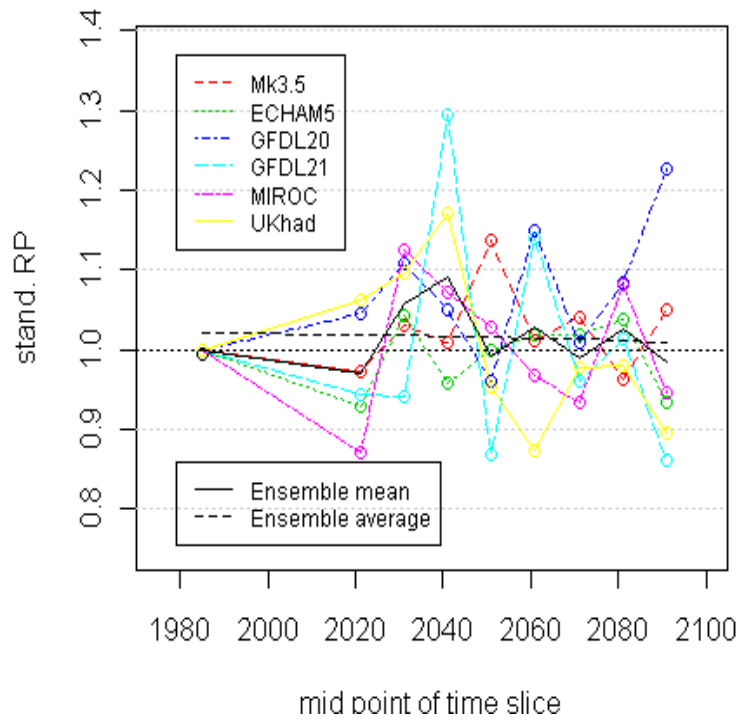


Figure 25. 500-yr RPs at Launceston Airport (A2 scenario).

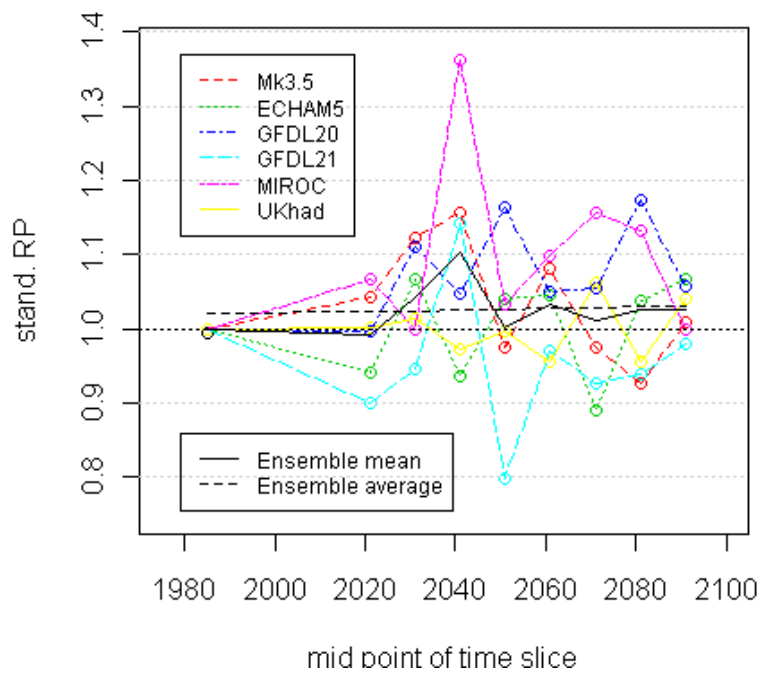
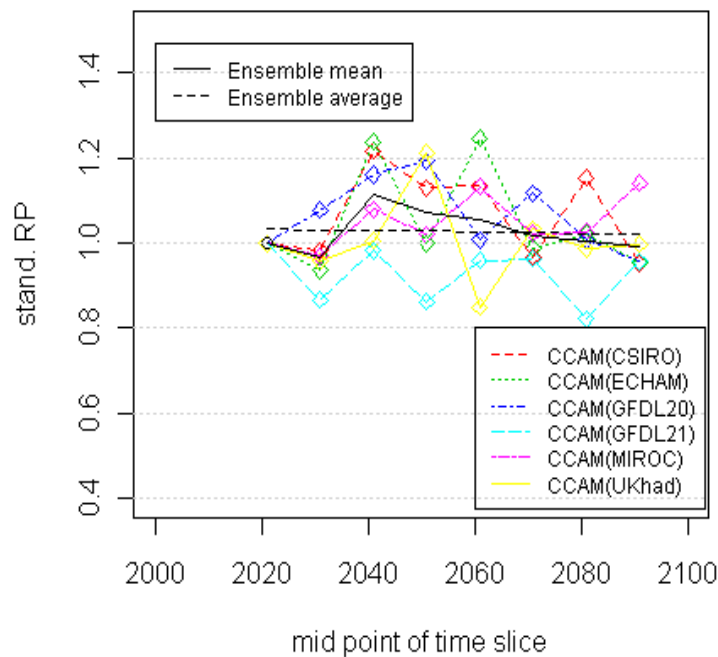


Figure 26. 500-yr RPs at Hobart Airport (A2 scenario).



**Figure 27.** 500-yr RP wind hazard at Hobart Airport (B1 scenario)

Table 8 shows the extreme value distribution (GPD) slope parameter trend over 21<sup>st</sup> century for the ensemble average (LR) for each of the three locations considered, with their 95% confidence interval (CI). The linear regression for Hobart and Wynyard have a very small positive slope indicating a very small increase in the long-term hazard, whilst for Launceston a very small negative slope indicates a very small reduction in hazard. It should be noted, based on all model results for all three locations, that there is a large CI for the future trend (slope), indicating a large uncertainty about the true long-term trend of synoptic wind hazard at these stations.

None of the trends for synoptic wind hazard at these locations are significant at the 95% confidence level (i.e. either positive or negative).

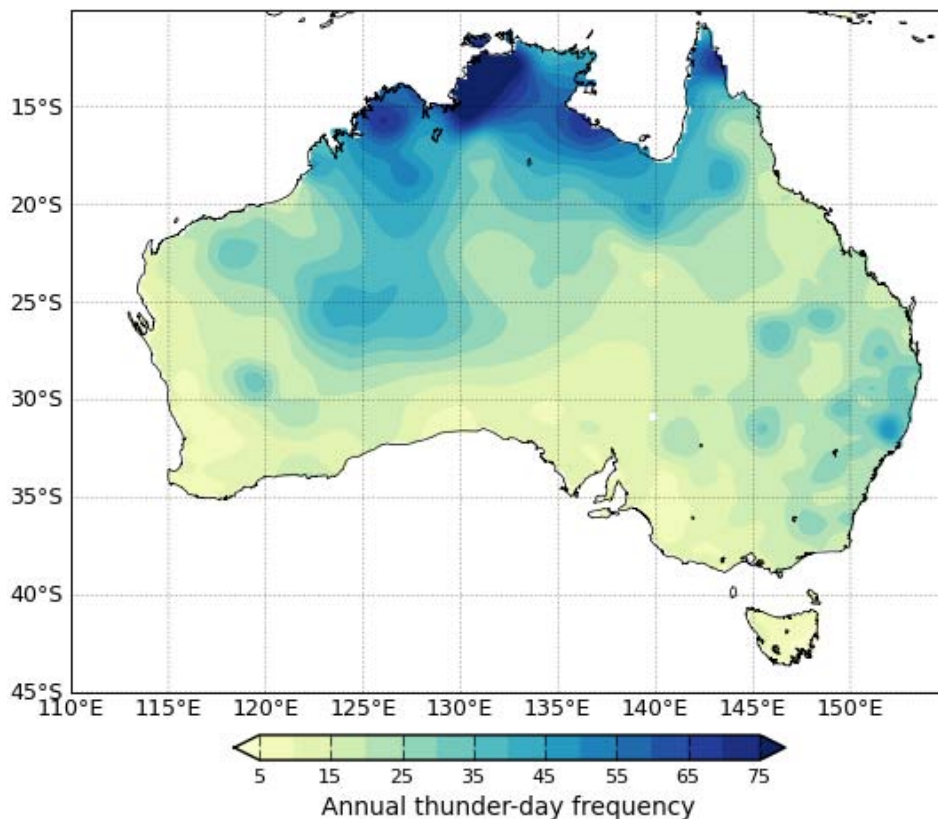
**Table 8.** Linear Regression (LR) parameters for ‘ensemble average’ (A2 scenario) for the Hobart, Launceston and Wynyard airport observing stations in Tasmania.

Location	Slope estimate	95% CI lower	95% CI upper
Hobart	0.0013	-0.0105	0.013
Launceston	-0.0014	-0.015	0.012
Wynyard	0.0034	-0.0072	0.014

### 3.3 MODELLED REGIONAL WIND HAZARD – THUNDERSTORM DOWNBURSTS

Thunderstorms are short-lived (on order of hours), localised convective weather events that are capable of generating wind gusts in excess of 50 m/s. While thunderstorms often also generate other severe weather phenomena such as hail, flash flooding and tornadoes, the focus of this study is the severe wind gusts thunderstorms are capable of generating and the resulting damage. For example ‘The Gap’ storm in November 2008 in Brisbane generated wind gusts estimated at 49 m.s<sup>-1</sup> and damaged over 700 buildings (Bureau of Meteorology 2011).

There is little knowledge of the spatial distribution of thunderstorm wind hazard. The distribution of thunder-days (days on which thunder is heard) and lightning flash rate have been used to estimate the frequency of thunderstorms across Australia (Kuleshov *et al.* 2006; Kuleshov *et al.* 2002), while Holmes (2002) investigated the effect of separation by storm type (i.e. thunderstorm or synoptic storm) for the capital cities [also Cook (2004) for Brisbane and Onslow]. To our knowledge, the intensity of wind gusts (and the resulting return period wind speeds) attributable to thunderstorms has not been mapped throughout the country. Figure 28 presents the current understanding of thunderstorm distribution, based on observations of thunder-days from approximately 300 stations across the country. The greatest number of thunder-days is across the tropical north of the country with areas surrounding Darwin exceeding 80 thunder-days per year. There is a higher frequency of thunder-days through the interior and over the eastern half of the continent, coinciding with the mean location of the summertime low pressure trough systems. The Tasmanian region experiences very few thunderstorms annually (on average). The frequency varies for 5 to 15 events, with relative maximum areas in the elevated regions along the entire west coast and in the northeast.



**Figure 28.** Average annual thunder-days, based on analysis of approximately 300 recording stations, averaged over the period 1990-1999. Data courtesy of Bureau of Meteorology.

### ***Thunderstorm model – Geerts (2001)***

Estimating the hazard posed by thunderstorm downbursts in future climate scenarios involves estimating both the intensity of thunderstorm downbursts and the frequency with which they currently occur. Unfortunately, the small scale of the process prevents direct physical modelling of thunderstorm downbursts over the long time periods that would be required to get satisfactory estimates of the hazard.

To investigate changes in downburst intensity an approach developed by Geerts (2001) was assessed. This involved taking a few thermodynamic variables and combining them in a simple formula (the GUSTEX index) that is intended to give an estimate of the maximum downburst wind that could be generated by a thunderstorm if such a storm developed in that environment. This approach was discarded both because the GUSTEX index gives no indication of the likelihood of a storm developing, and because it was found that the estimates provided by the GUSTEX index did not verify well against radiosonde, anemometer and weather description data provided by the Bureau of Meteorology. However it must be said that it is difficult to perform such verification and there is room for further work in this area.

### ***Thunderstorm model – Trapp index to assess thunderstorm frequency***

Whilst there is currently no way to estimate possible changes in thunderstorm intensity in future climates, there has been a technique developed to estimate changes in thunderstorm frequency. Brooks *et al.* (2003) developed an index based on wind shear and convective available potential energy, both of which can be obtained from observations and also from downscaled global circulation models. They showed that this index could be used to discriminate between environments that are likely to produce severe convective storms, and those that are not. Subsequently Trapp *et al.* (2007) used a simplified version of this index to estimate changes in severe thunderstorm environment frequency during the 21<sup>st</sup> century.

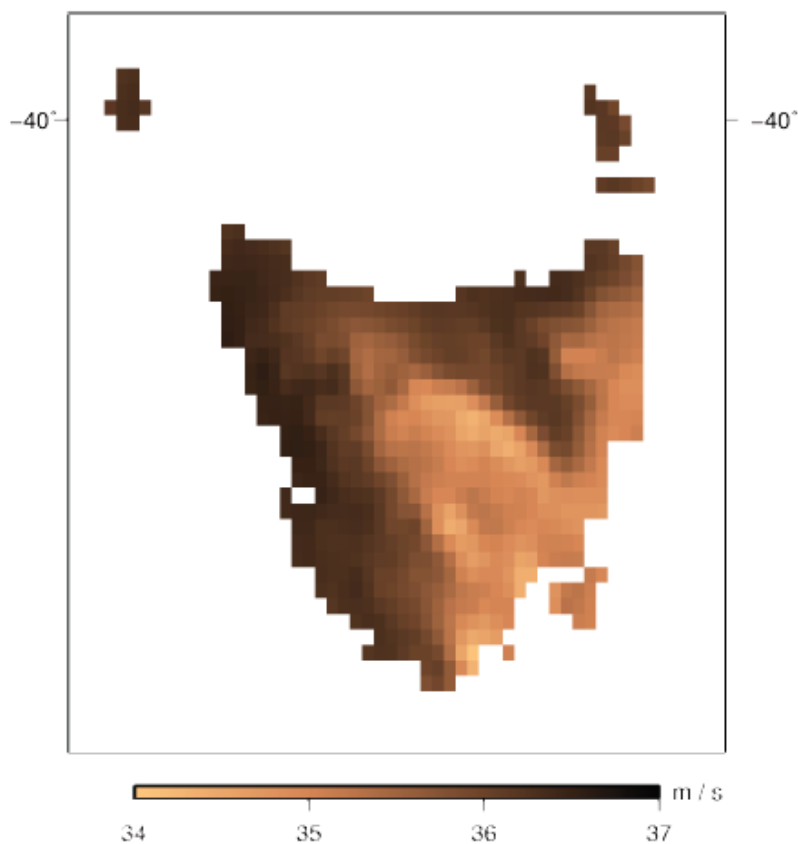
Thus, in estimating changes in thunderstorm hazard for the Tasmanian region, it has been assumed that the intensity distribution of thunderstorm downbursts remains the same as in the current climate (because there is no way of modelling how it might change) and the Trapp methodology has been used to estimate possible changes in thunderstorm frequency. The current climate hazard has been estimated from observational data at the Bureau of Meteorology stations at Tasmanian airports in the study region. Climate model data obtained by downscaling the global circulation models CSIRO's Conformal-Cubic Atmospheric Model – CCAM, have been used to compute the Trapp index for the current climate and for future periods in the 21st century. These results have then been applied to modify the frequency of thunderstorm winds observed from the BoM data. More precisely, the probability of exceedance of the thresholds used to fit Generalised Pareto Distributions (GPD) to the BoM data have been modified using estimates of thunderstorm environment frequency from the Trapp index.

### ***Current climate thunderstorm hazard in Tasmania***

NCEP/NCAR reanalysis data were downscaled resulting in a dataset of historical atmospheric conditions for 1961-1990 with a resolution of approximately 14 kilometres. There are only two suitable BoM observing stations for long-term extreme wind measurements, Launceston and Hobart airports, making spatial interpolation of thunderstorm observations unsuitable. The Wynyard observing site has less than 15 years of wind gust observations and was joined with the Launceston site for synoptic wind hazard evaluation. The Hobart and Launceston observational datasets were combined and the extreme value analysis was applied to the combined dataset. Rather than use this single distribution over the entire state, the current climate (1961-1990) Trapp index exceedance frequencies were computed using the downscaled NCEP/NCAR reanalysis data (described in [Section 3.2](#)), and the value of the shape parameter ( $\zeta$ ) of the extreme value distribution was varied spatially by comparing the ratio of the Trapp index exceedance frequencies at a general pixel to that at the pixel containing the combination of Hobart and Launceston airports. Specifically

$$\zeta_{\text{pixel}} = \frac{\text{NCEP Trapp index exceedance frequency at pixel} \times 5.353 \times 10^{-3}}{\text{NCEP Trapp index exceedance frequency at Hobart}}$$

Essentially, in the absence of more observational data, this procedure amounts to assuming that thunderstorm intensity is constant over the state under the current climate, and therefore that the hazard varies spatially according to the variation in thunderstorm frequency. The resulting spatial 500 year thunderstorm hazard exceedance levels are shown in Figure 29. Notice that the thunderstorm wind hazard magnitude for Launceston and Hobart are not the same reflecting the higher number of thunderstorms observed in the Launceston region. A comparison of Figure 29 with the current climate synoptic hazard (Figure 19) indicates that the thunderstorm hazard is lower than the synoptic hazard for the majority of the Tasmanian region.



**Figure 29.** Estimated spatial variation in current climate thunderstorm hazard over Tasmania. Shown is the 500-year return-period exceedance levels for thunderstorm wind gust hazard (10 metre height). Extreme value analysis (GPD) was applied to the combined observational datasets from Launceston and Hobart airports. The resulting probability of exceedance was varied spatially in relation to the variation of the Trapp exceedance frequencies computed using downscaled NCEP reanalysis data for the period 1961-1990. All other GPD parameters were held constant.

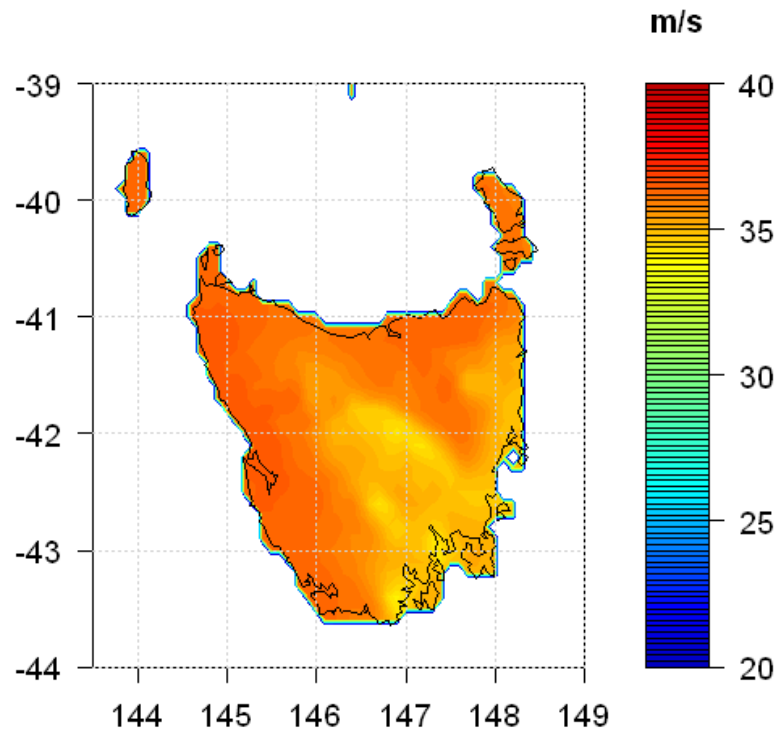
***Estimates of changes in thunderstorm hazard in Tasmania under future climate scenarios***

The results from the previous section can be used to obtain some indication of how the thunderstorm hazard in Tasmania may change in the future. For reasons outlined above, it is not currently possible to model thunderstorm intensity and therefore it is not possible to make an assessment of how this may change under future climate scenarios. However some research considering the type of environmental atmospheric conditions that contribute to the formation of thunderstorms has been

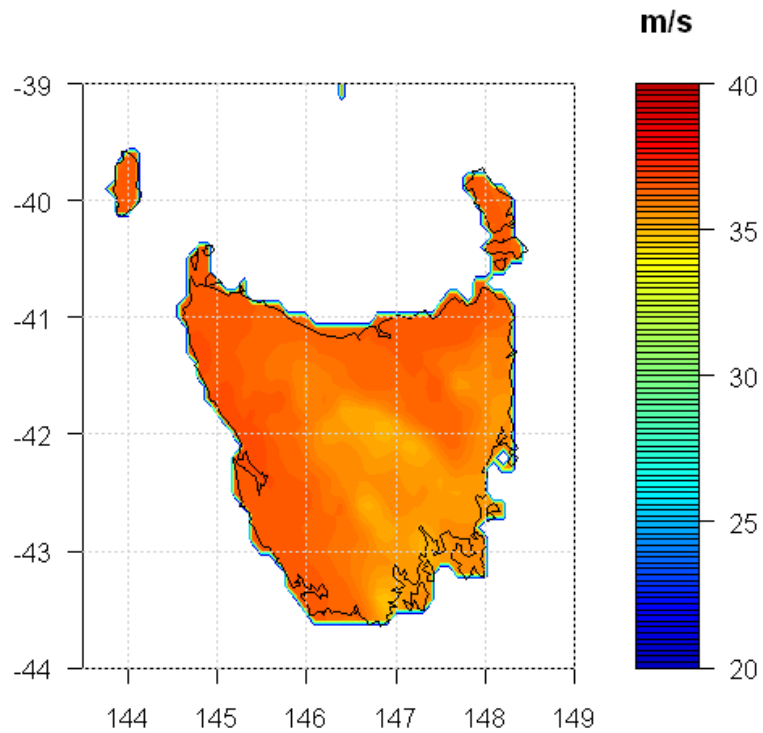
undertaken, thereby making it possible to get an understanding of plausible changes in thunderstorm frequency under future climate scenarios. Because it is not possible to make an assessment of how the intensity of thunderstorms might vary in the future, the analysis presented in this section is based on the assumption that the intensity remains the same, and the effect on thunderstorm downburst gust hazard of changes in frequency alone is examined.

This analysis has been applied spatially. If thunderstorm intensity is assumed to remain constant over a region, then variations in storm frequency throughout the region are reflected in variations in the hazard. It should be noted that if exceedance level curves are relatively “flat” (i.e. little change in hazard with return period), then quite large changes in frequency may not have a great effect on exceedance levels. For example, if thunderstorm frequency is doubled then a 1000 year exceedance level can now be expected to recur on average every 500 years. If the exceedance level curves are relatively flat, then there may not be a large difference between these values. In the case of the observed Hobart record of gust wind speeds, a doubling of thunderstorm frequency would result in an increase of only 3 to 4 m/s in the 500 year exceedance level (still below synoptic hazard levels).

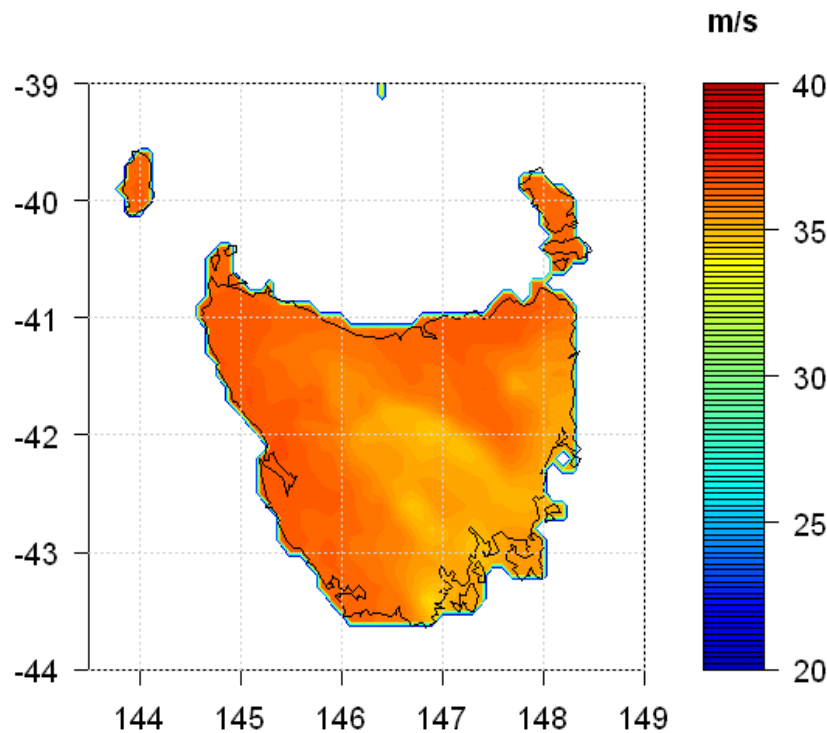
If the current climate hazard has been determined using a generalised Pareto distribution, with threshold  $u$ , then the changes in frequency are reflected by a change in the probability of exceedance. This analysis is undertaken over the model grid (i.e. GPD thresholds, parameters and exceedance probabilities has been produced along with a grid of frequency ratios). The modified hazard is obtained by multiplying the exceedance probabilities by the ratio of the Trapp index exceedance frequencies. For Tasmania, threshold  $u$  and GPD parameters were determined from the combined observed dataset from Launceston and Hobart airports, and are assumed to be constant over the entire state. The probabilities of exceedance for the current climate have been modified spatially as described above, and the results of the ensemble mean of the simulations have been used to multiply (scale) the current climate values. The results for the A2 scenario and three time periods under consideration (current climate, 2050 and 2090) are shown in [Figures 30, 31 and 32](#). It is apparent that the changes in thunderstorm frequency estimated using this procedure do not result in large changes in hazard, as discussed above.



**Figure 30.** 500year return-period (RP) of thunderstorm gust hazard, (A2 scenario model simulations for 1961-1990; current climate).



**Figure 31.** 500year return-period (RP) of thunderstorm gust hazard, (A2 scenario model simulations for 2041-2060; representing 2050).



**Figure 32.** 500year return-period (RP) of thunderstorm gust hazard, (A2 scenario model simulations for 2081-2100; representing 2090).

### 3.4 MODELLED REGIONAL WIND HAZARD – COMBINED HAZARD

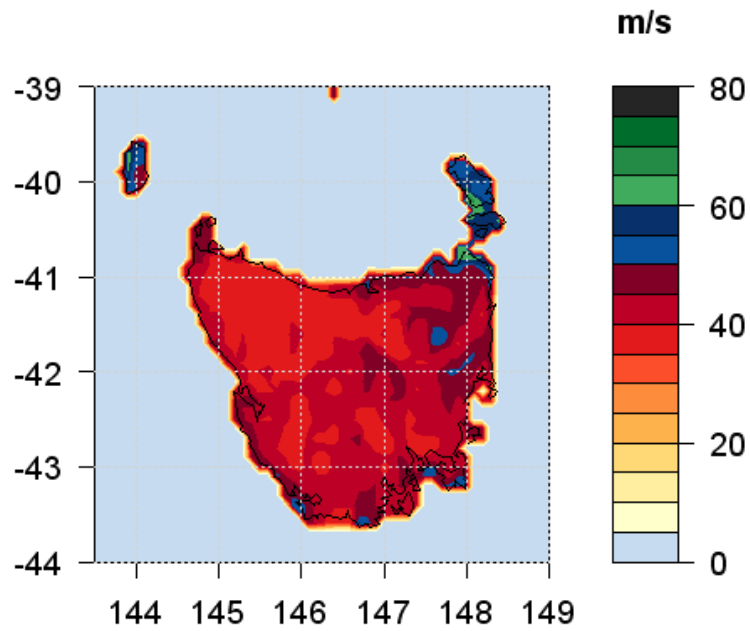
It is necessary to combine the estimates of the individual hazards, thunderstorms and synoptic winds, to form an estimate of the combined hazard. This is achieved by using a probabilistic formula which computes the return period of the combined wind hazard at a particular exceedance level in terms of the return periods of each of the constituent wind hazards at that level. Using Equation 4, for any given return period, for example 50 years, the equation  $t_{comb}(w) = 50$  can be solved for  $w$  to find the wind gust level giving an expected period between exceedances of 50 years (the so called 50 year exceedance level).

$$t_{comb}(w) = \left[ 1 - \left( 1 - \frac{1}{t_s(w)} \right) \left( 1 - \frac{1}{t_t(w)} \right) \right]^{-1} \quad \text{Equation 4.}$$

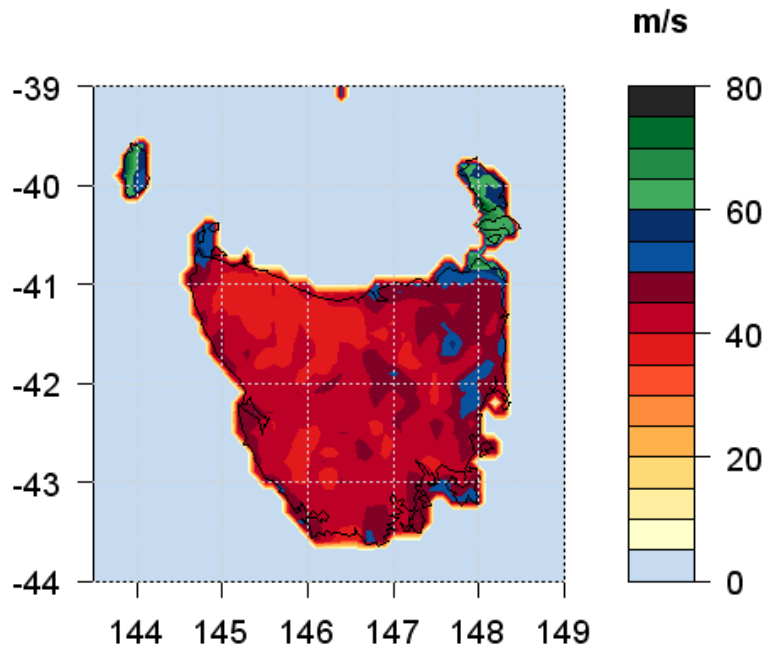
where  $t_{comb}(w)$  is the return period of the combined wind at an exceedance level  $w$ , and,  $t_s(w)$  and  $t_t(w)$  are the return periods of the cyclonic, synoptic and thunderstorm winds at that level.

The exceedance levels for the combined wind hazard will necessarily always be greater than those associated with each of the individual hazards. However in the case where one hazard dominates the others, the combined hazard will be close to that of the single dominant hazard. For example, the thunderstorm hazard across the central valley/plains of Tasmania is significantly lower than the hazard from synoptic events. This results in the combined hazard closely matching the synoptic hazard map.

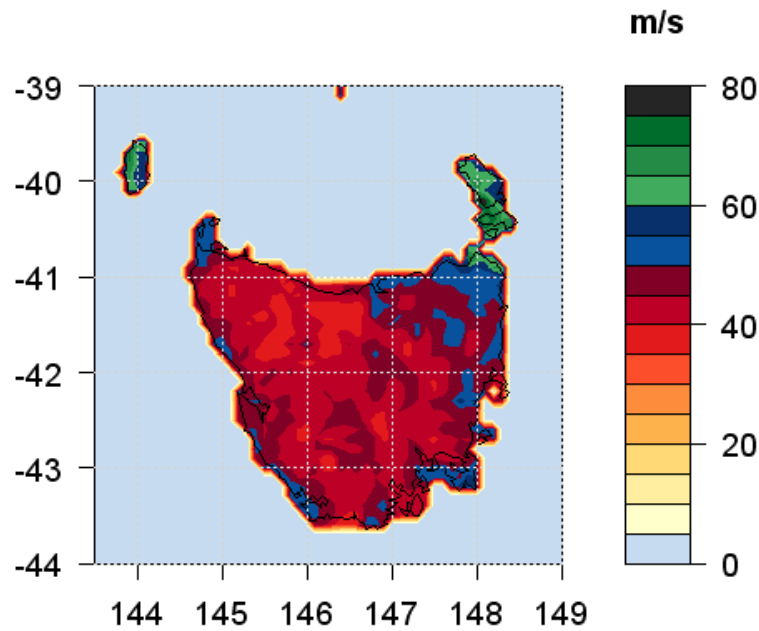




**Figure 33.** 500year return-period (RP) of combined gust hazard, (1961-1990; current climate).

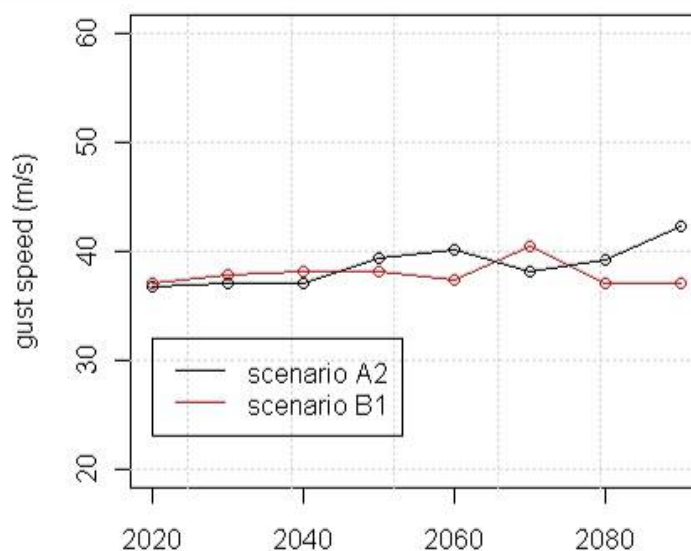


**Figure 34.** 500year return-period (RP) of combined gust hazard, (A2 scenario model simulations for 2041-2060; representing 2050).



**Figure 35.** 500year return-period (RP) of combined gust hazard, (A2 scenario model simulations for 2081-2100; representing 2090).

The combined wind hazard results for the A2 climate change scenario and for three time periods (current climate, 2050 and 2090) are shown in Figures 33, 34 and 35. It is apparent that the changes in wind hazard using the methodology described above do not result in large changes in hazard, however there are some interesting regional patterns where hazard increases in some regions and decreases or stays at similar levels in other regions. This is considered further by investigating some specific locations around Tasmania. Figure 36 displays the gust wind speed hazard for Hobart Airport. Both the B1 and A2 climate change scenarios are shown and the data for decadal (10-year) assessments of wind hazard is plotted (6 GCM model ensemble). For the B1 scenario there appears to be no trend with time however for the high greenhouse gas emission scenario (A2) there appears to be a weak trend towards increasing hazard.



**Figure 36.** Model ensemble average of 500year RP hazard for combined winds at Hobart Airport. Data representing the hazard of the mid-point for each time slice are shown.

The results displayed in [Table 9](#) highlight the differences in outcomes for the two climate change scenarios (B1 and A2). Shown is the 500 year combined gust wind speed hazard (model ensemble average) for a range of locations over the Tasmanian region. Results for three airport locations as well as three locations in the east of the state are shown. For each time-period and location the 500 year RP values for the A2 scenario are displayed above those for the B1 scenario. The values for the two scenarios appear to diverge towards the end of the 21<sup>st</sup> century, with the hazard level maintained for the B1 scenario whereas small increases are evident for the A2 scenario.

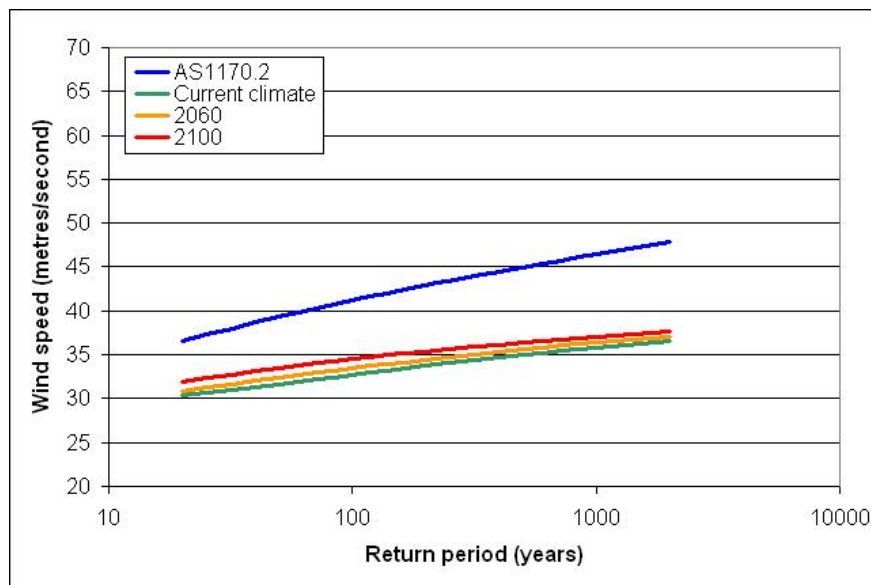
**Table 9.** 500year RP of combined gust wind speeds (GCM model ensemble average) for locations shown

Time: period	Scenario	Hobart	Launceston	Wynyard	Scottsdale	Bicheno	Cranbrook
2020: 2011-2030	A2	38.6	39.3	37.8	43.2	45.9	45.8
	B1	37.0	38.9	37.6	42.4	45.0	45.1
2030: 2021-2040	A2	37.1	38.6	37.5	41.2	45.7	45.8
	B1	37.9	39.2	37.7	42.9	47.2	44.0
2040: 2031-2050	A2	37.0	39.4	38.7	43.1	45.7	44.9
	B1	38.2	40.7	38.4	40.9	47.1	46.8
2050: 2041-2060	A2	39.3	41.0	40.6	45.4	47.3	47.1
	B1	38.1	40.6	38.8	42.3	47.0	46.6
2060: 2051-2070	A2	40.2	40.6	39.4	45.3	47.5	45.6
	B1	37.4	40.3	37.2	42.5	47.2	45.6
2070: 2061-2080	A2	38.1	39.8	39.5	47.4	50.7	46.1
	B1	40.4	40.3	37.0	42.9	46.7	46.3
2080: 2071-2090	A2	39.2	41.2	41.8	47.1	50.6	47.5
	B1	37.0	38.4	37.9	44.0	47.3	46.5
2090: 2081-2100	A2	42.3	46.6	40.6	46.7	49.6	48.5
	B1	37.1	39.6	37.2	43.3	47.9	46.3

### 3.5 MODELLED REGIONAL HAZARD – COMPARISON WITH AS/NZS 1170.2

The Australian Standard/New Zealand Standard 1170.2 *Structural design actions Part 2; Wind actions* sets out the regional wind speeds that must be used in calculating loads for the design of engineered and residential structures in different regions of the country, across a range of sites (e.g. medium-density urban, open country, or on sloping sites). These “*design wind speeds*” are equivalent to wind hazard in that they are determined utilising a similar methodology (extreme value statistics) employed on observations (wind gusts) for describing wind hazard. They are described in terms of a return period, and the level of hazard is set to the 500 year return period for all residential housing applications in the Australian region. The levels are set in an effort to equalise the risk between the low and high hazard regions across the country.

It is therefore very useful to compare the 500 year return period hazard levels determined in this study with the wind loading standard (AS/NZS 1170.2), especially as our determination involves both a spatial assessment of the hazard and also how it may be influenced by climate change. The comparison is carried out by first considering the Hobart region (where a large percentage of residential structures are located), as well as a comparison across the whole state. [Figure 37](#) compares AS/NZS 1170.2 (same level for all Tasmania) with the hazard for Hobart across all return periods for the A2 scenario (current climate, 2060 and 2100 considered). The hazard level for this high emissions scenario is well below the current wind loading standard and remains so for the Hobart region to the end of the 21<sup>st</sup> century.



**Figure 37.** Return-period wind hazard under current and future climates for the Hobart region (A2 scenario). Also shown is the regional wind speed as defined by AS/NZS 1170.2 (2011).

The Hobart airport gust wind speed measurements (1958- ) are used in AS/NZS 1170.2. It should be noted that wind speeds recorded in the built-up area of Battery Point (Ellerslie Rd; 1944- ) contain significantly higher gust wind speed measurements compared to the open-plain airport site. There are two main reasons why the Ellerslie Rd site has measured higher gust speeds and its measurements was not considered for this study:

- (1) the site is in an urban setting with a 3 storey building located within 15 metres away from the mast since the late 1950's (see Figure 38) resulting in turbulent effects and possibly funnelling in some directions. Figure 39 shows a photograph of the anemometer mast viewing the site to the WSW (recent redevelopment of 1950's structure);
- (2) the mast is 20 metres high (standard height is 10 metres) and therefore is exposed to higher wind speeds (approx 25% employing an exponential wind profile; see Holmes, 2007) in the boundary layer.



**Figure 38.** Battery Point (Hobart) Ellerslie Rd. meteorological observing site illustrating the urban setting surrounding the anemometer mast.



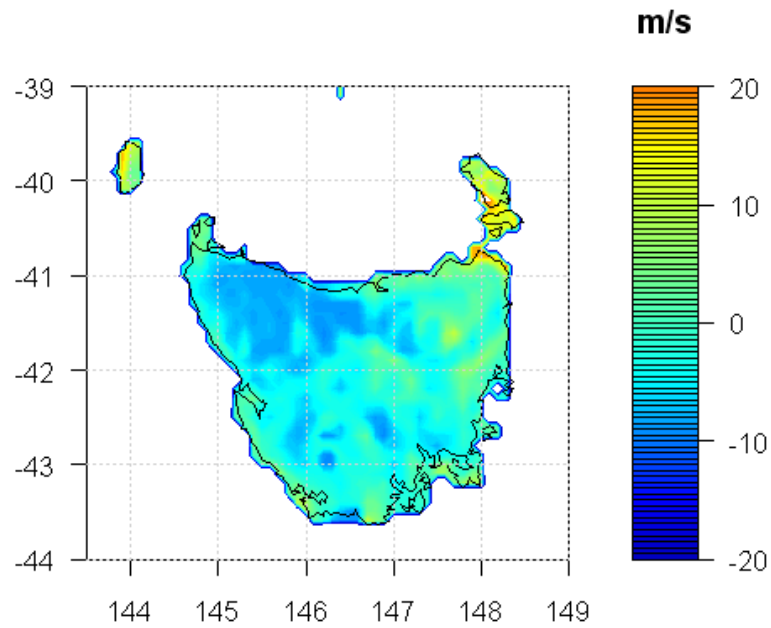
**Figure 39.** Battery Point (Hobart) Ellerslie Rd. meteorological observing site with 20 metre anemometer mast (view to WSW illustrating the redevelopment of a 3-storey structure). Image supplied by the Bureau of Meteorology, Hobart office.

Table 10 displays the regional wind hazard estimates for the Hobart region (in m/s) considering current climate as well as 2060 and 2100 (B1 and A2 emissions scenarios). The design wind speed (500year return period hazard) based on AS/NZS 1170.2 is also shown and is well above the hazard determined by this study. This indicates that for the Hobart region AS/NZS 1170.2 remains a conservative estimate of wind hazard and its utility is maintained to the end of the 21<sup>st</sup> century.

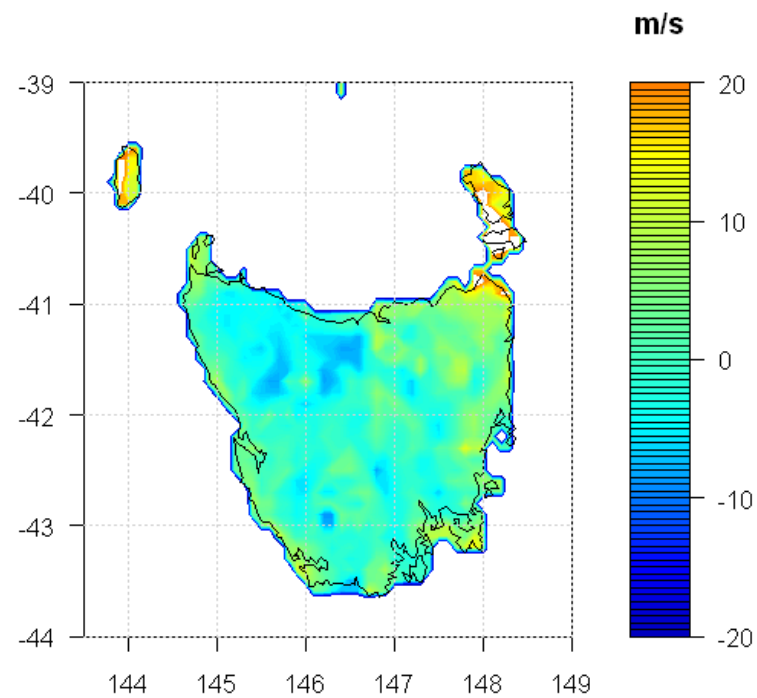
**Table 10.** Regional wind hazard estimates (m/s) for 2060 & 2100 for the Hobart region considering two emissions scenarios (B1 and A2; ensemble model average). The design wind speed (500year return period hazard) based on the AS/NZS 1170.2 hazard level (and for all scenarios) are also included.

RETURN PERIOD	AS/NZS 1170.2	B1 2060	B1 2100	A2 2060	A2 2100
20 yrs	36.6	30.6	31.1	30.7	31.7
50 yrs	39.3	32.1	32.5	32.2	33.2
100 yrs	41.1	33.2	33.5	33.3	34.2
200 yrs	42.9	34.2	34.5	34.3	35.1
<b>500 yrs</b>	<b>45.0</b>	<b>35.4</b>	<b>35.6</b>	<b>35.5</b>	<b>36.2</b>
1000 yrs	46.5	36.2	36.4	36.3	36.9
2000 yrs	47.8	36.9	37.1	37.0	37.5

Comparison of the modelled 500 year return period hazard with AS/NZS 1170.2 for the whole of the Tasmanian region is considered in Figures 40 and 41 (shown is the difference between AS/NZS 1170.2 and the modelled hazard). For the current climate hazard mainly the northeast of the state and Bass Strait islands have a modelled hazard above the level of hazard in the wind loading standard. The majority of the state has a modelled hazard below the level of hazard in the wind loading standard (shown as blue and aqua regions). For 2090 (A2 scenario) a slightly greater portion of the state has a modelled hazard above the wind loading standard however the major population centres have a modelled hazard below the wind loading standard.



**Figure 40.** Wind speed difference (m/s) between current climate 500 year return-period wind hazard and the wind hazard as defined in AS/NZS 1170.2 (2011).



**Figure 41.** Wind speed difference (m/s) between 2090 A2 scenario 500 year return-period wind hazard and the wind hazard as defined in AS/NZS 1170.2 (2011).

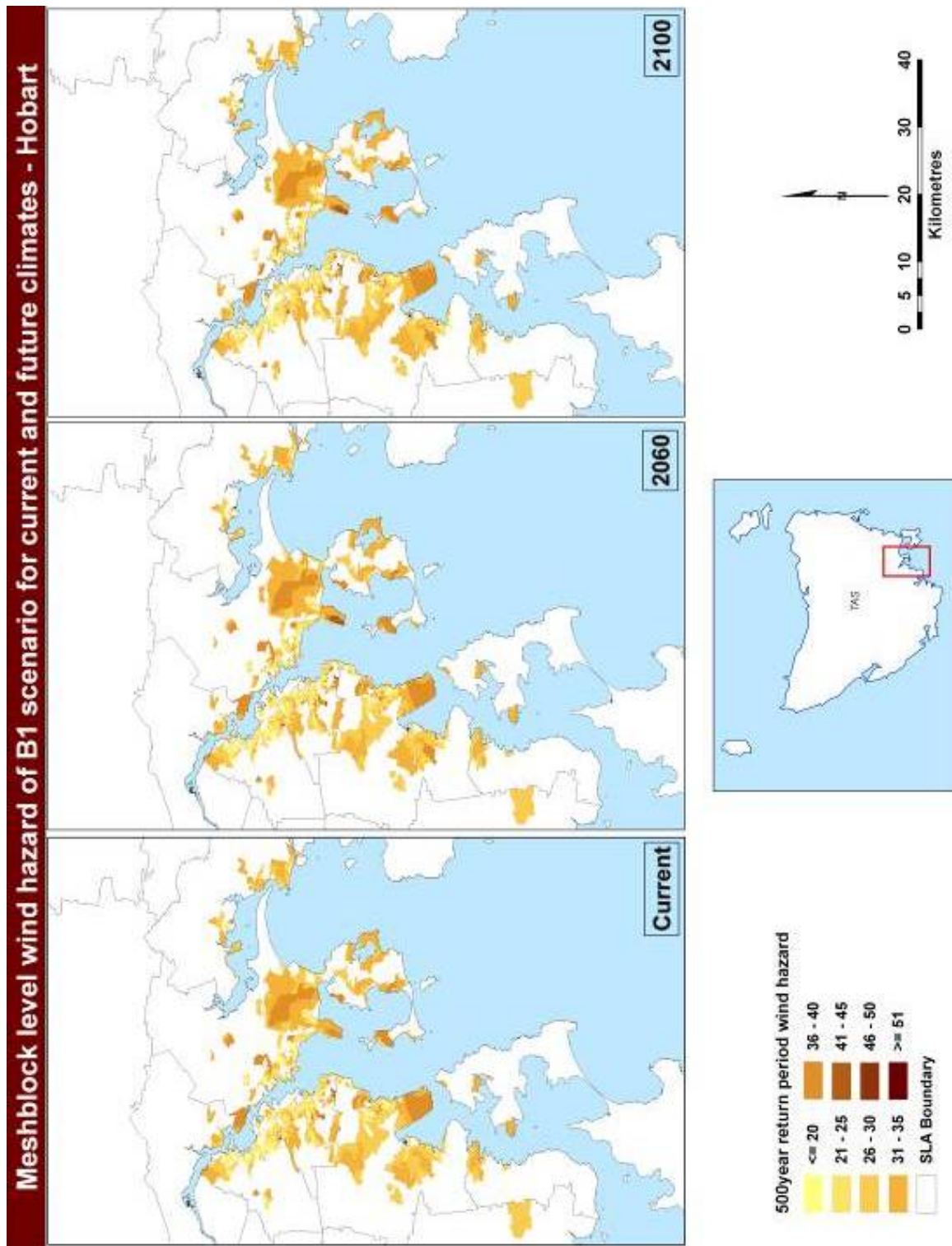
### 3.6 MODELLED LOCAL HAZARD – COMPARISON WITH AS4055 WIND CLASSES

As detailed in [Section 2.2.1](#), wind vulnerability for residential buildings is tied to the detailing of the structure which in turn is tied to the AS 4055 (2006) *Wind loads for housing* hazard classification. AS/NZS 1170.2 (2002) sets out the design gust wind speeds (that relate to the performance levels specified in the Building Code of Australia; BCA) that must be used in calculating loads on structures in different regions of the country.

[Table 3 \(Section 2.2.1\)](#) details the AS 4055 wind classes and design wind speeds which are categorised into six classes within the non-tropical regions (N1 to N6) and four classes within the tropical regions (C1 to C4). These classes consider the combination of the regional wind speed, the directional multiplier and the three site exposure multipliers (terrain, shielding and topography). The AS/NZS 1170.2 non-tropical regions are Regions A & B and the tropical regions (higher design wind speeds) and Regions C & D. All residential structures built since the early 1990's have been classified either N1 – N6 or C1 – C4 based on their site wind speeds.

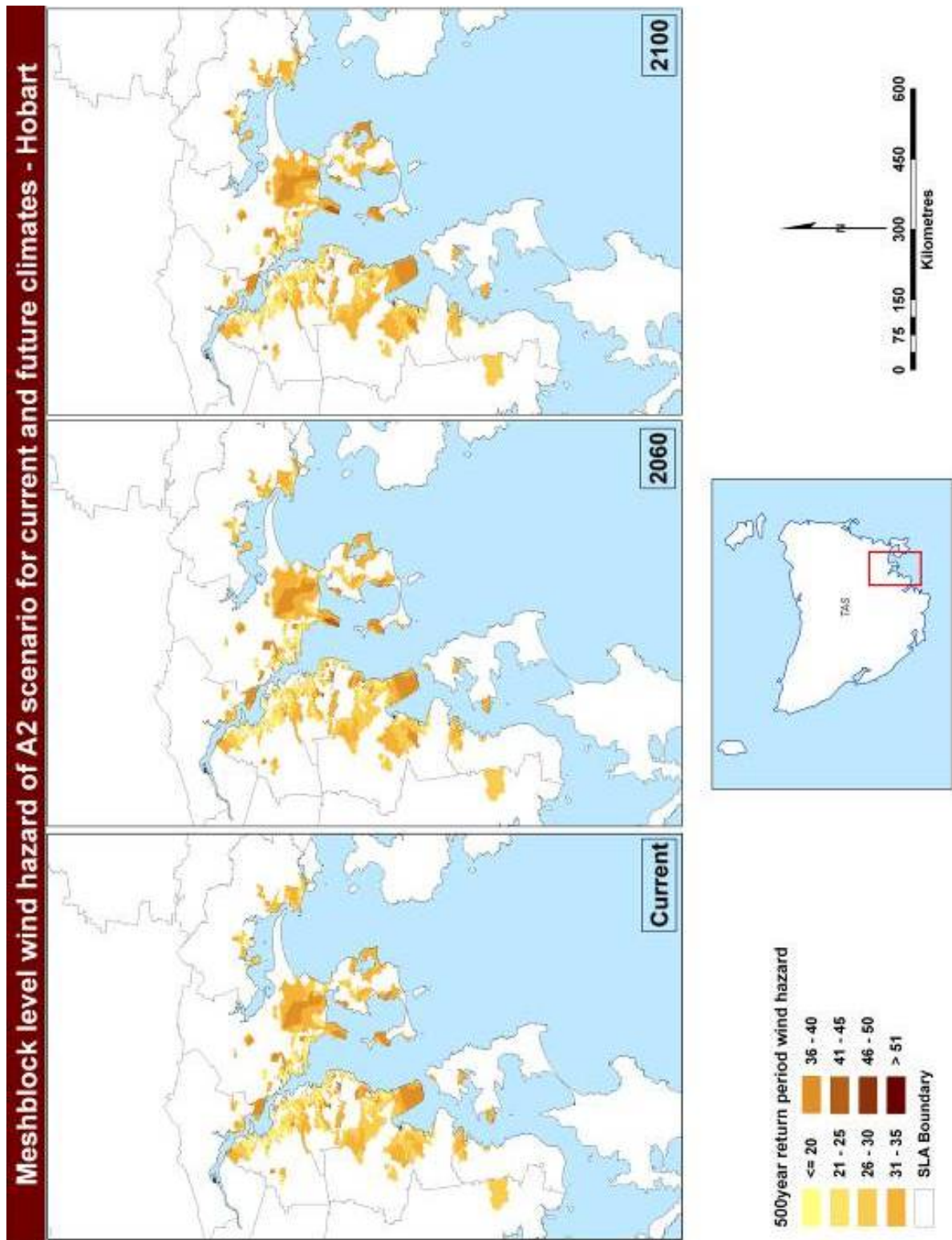
We have explored how the AS 4055 categorisation for Hobart may be affected by climate change. The categorisation is directly linked to the future hazard assessment. [Figure 42](#) maps the 500 year return period gust wind speed hazard across the Hobart region for the B1 scenario. [Figure 43](#) maps the corresponding hazard for the A2 scenario. For both these figures the hazard is aggregated to Australian Bureau of Statistics (ABS) meshblock level (smallest aggregation of statistical information). There is little difference in the hazard for both scenarios and time segment (i.e. 2060 and 2100) for the Hobart region which is consistent with [Figure 38](#) (shows the full return period spectrum for the Hobart region).

[Figure 44](#) shows the AS4055 classes for the Hobart region for current climate and for the A2 scenario at 2060 and 2100. As the modelled hazard for the Hobart region is much lower than the AS/NZS 1170.2 hazard (see [Figure 37](#)), the results display a very flat classification where only low wind speed classes are depicted. [Figure 45](#) maps the difference in AS4055 wind classes for the 2060 and 2100 time periods (A2 scenario). Both these maps also utilise the ABS *mesh block* local spatial aggregation. Little change in classes is evident in [Figure 45](#) due to the relatively small change in wind hazard shown in [Figure 37](#).



**Figure 42.** 500 year return period gust wind speed hazard across the Hobart region for current climate and at 2060 and 2100 for the B1 climate change scenario. The hazard has been aggregated to Australian Bureau of Statistics (ABS) meshblock level.





**Figure 43.** 500 year return period gust wind speed hazard across the Hobart region for current climate and at 2060 and 2100 for the A2 climate change scenario. The hazard has been aggregated to Australian Bureau of Statistics (ABS) meshblock level.

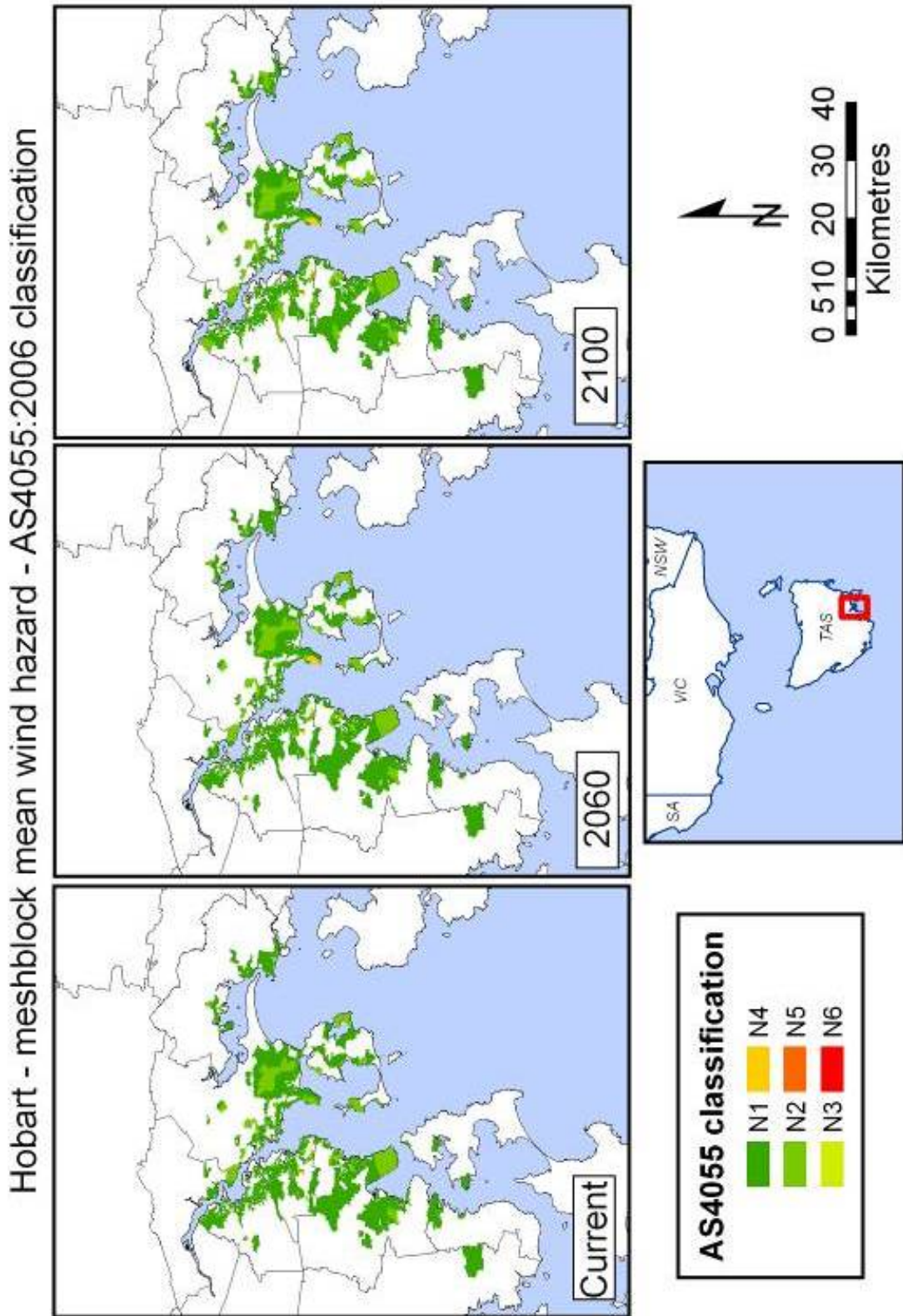
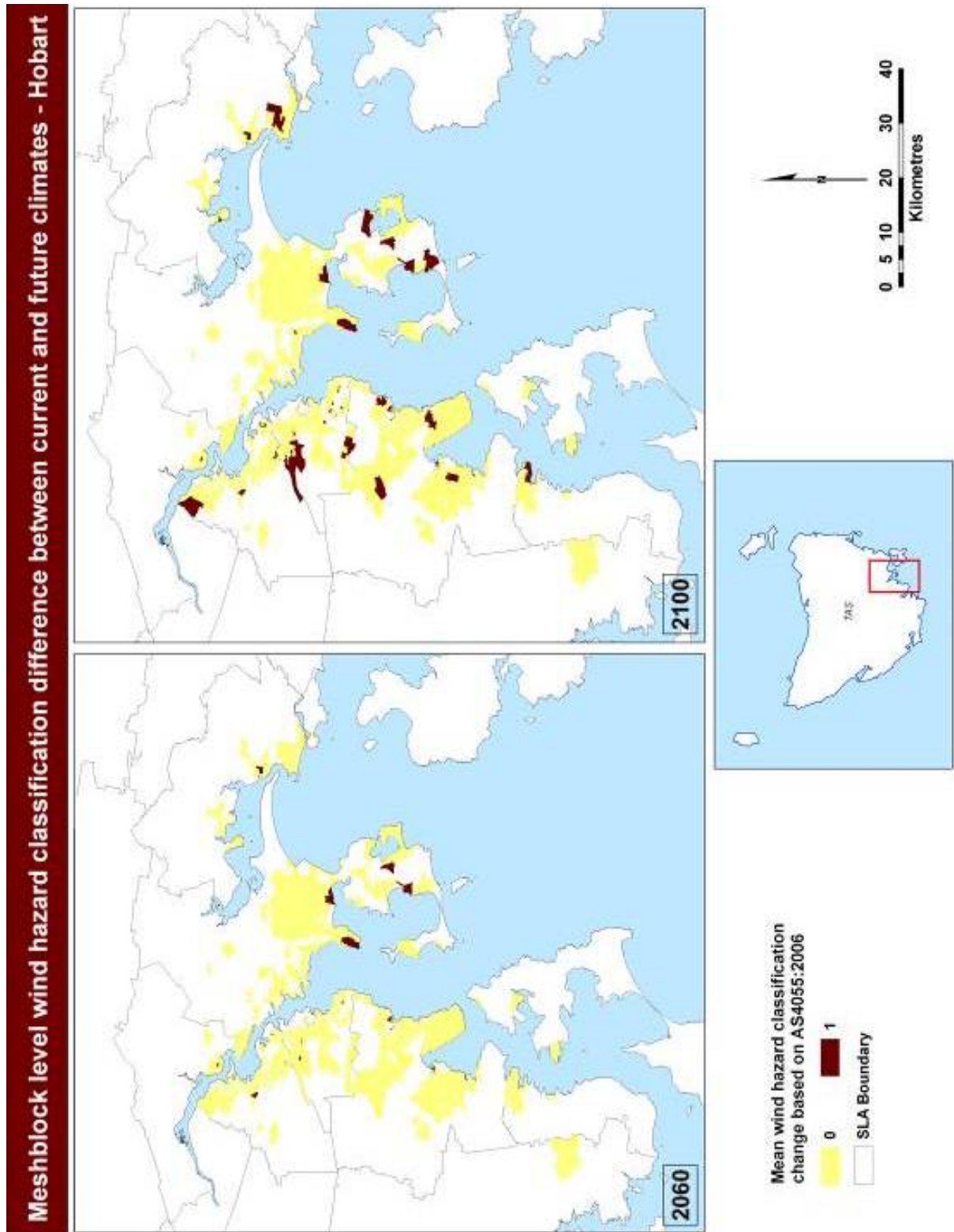


Figure 44. AS4055 classes for the Hobart region for current climate and for the A2 scenario at 2060 and 2100. Data aggregated to ABS meshblock regions.



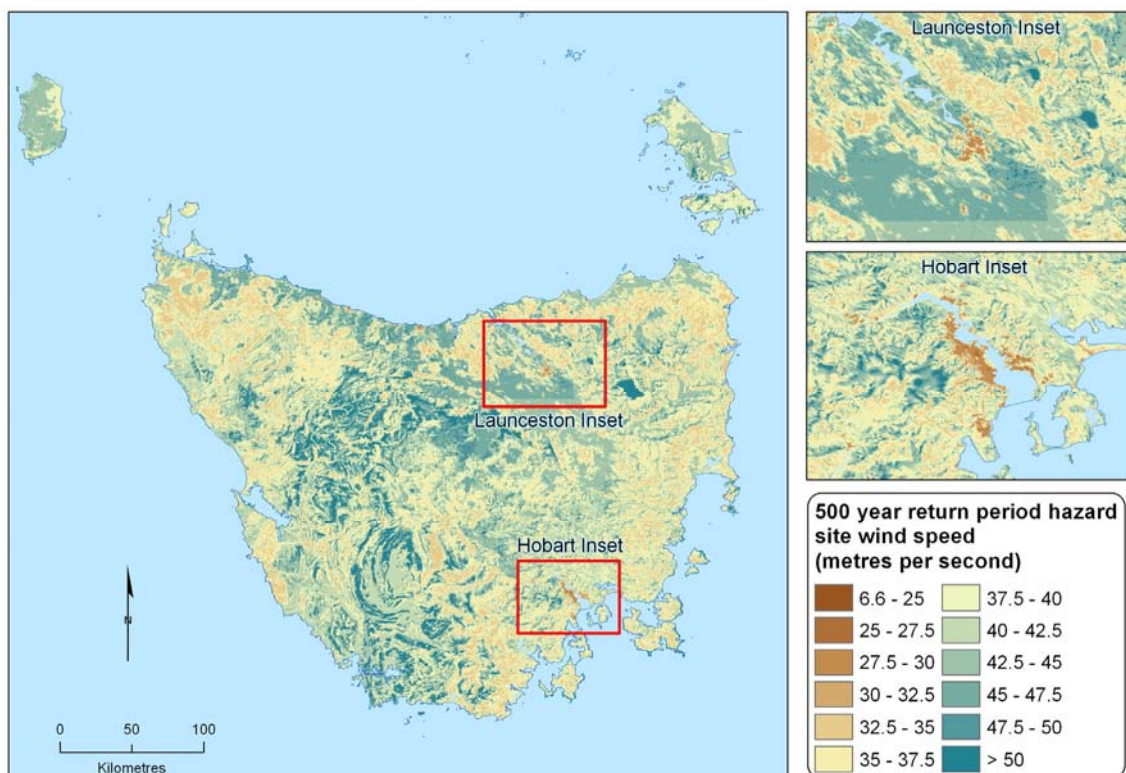
**Figure 45.** Difference in AS4055 wind classes (local hazard classification) for the 2060 and 2100 time periods (A2 scenario). Data aggregated to ABS meshblock regions.

## 4. Wind Risk

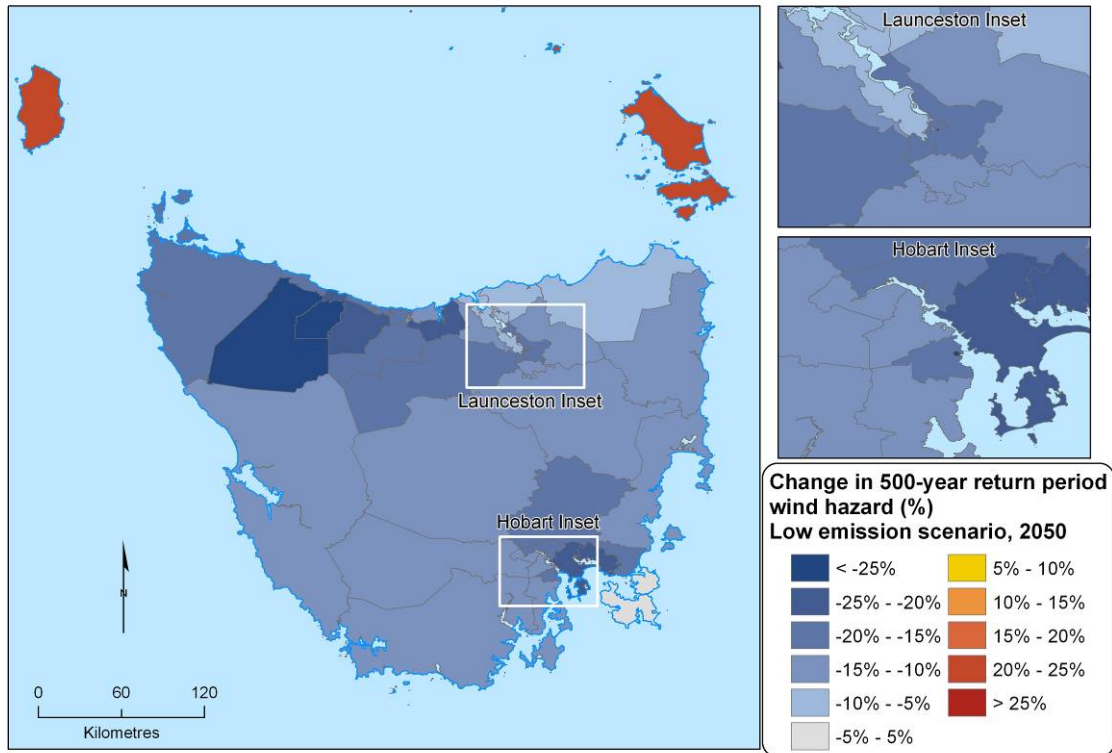
The Tasmanian wind risk assessment of residential buildings was evaluated using the regional design wind speeds detailed in Section 3. The methodology to determine local wind hazard (hazard at the building scale) and the subsequent wind risk is detailed in Section 2. The techniques utilised to evaluate wind risk at a local scale (buildings level) provide a preliminary estimate of wind risk based on current knowledge. The classification of building age and type with appropriate wind vulnerability curves is applied, and the local wind effects are incorporated through the wind multipliers. The wind risk evaluation for both current climate and the climate change scenarios is presented aggregated at the Statistical Local Area (SLA) level. The reasoning here is twofold; consideration of privacy issues and also errors associated with household estimates being averaged out by considering area estimates.

### 4.1 LOCAL WIND HAZARD

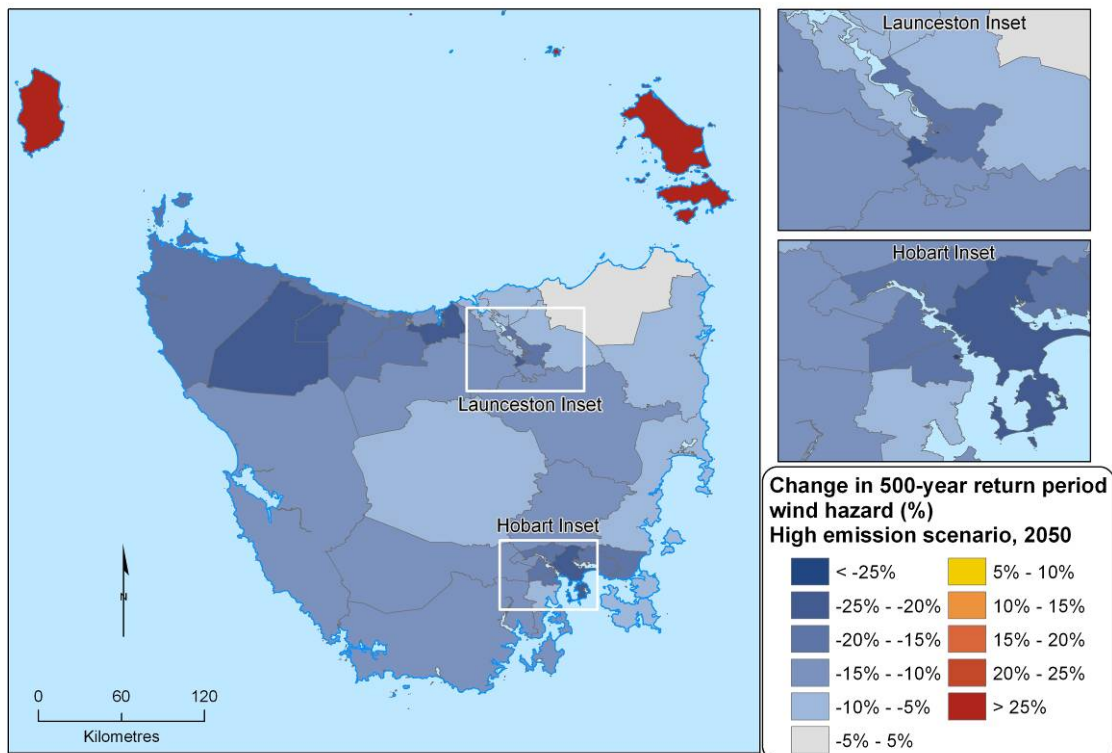
Firstly the local wind hazard is presented, also aggregated to the SLA level, with a focus on the spatial texture and the extent to which it varies from current climate hazard. Figure 46 shows the 500 year return period current climate local “site” wind hazard for the Tasmanian region. Figures 47 to 50 display the difference between the 500 year return period current climate local wind hazard and that projected for 2050 and 2090 considering the B1 and A2 climate change scenarios (all data aggregated to SLA region).



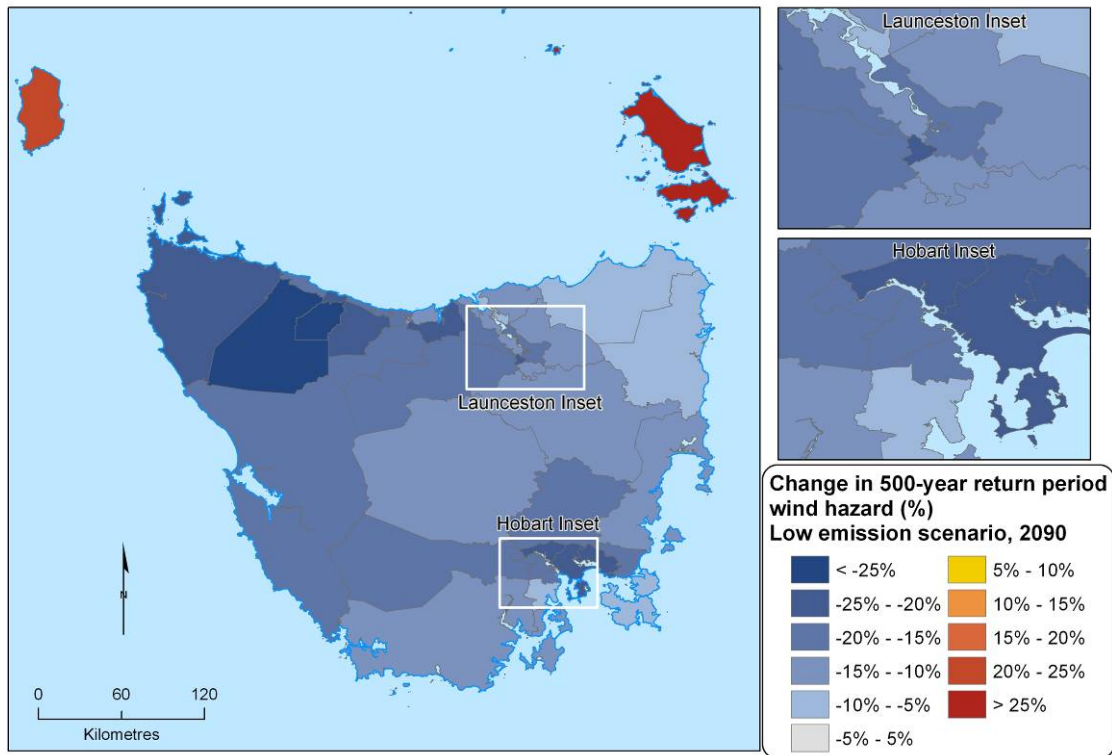
**Figure 46.** Local (site) wind hazard- current climate (500 year return period) in m/s for the Tasmanian region.



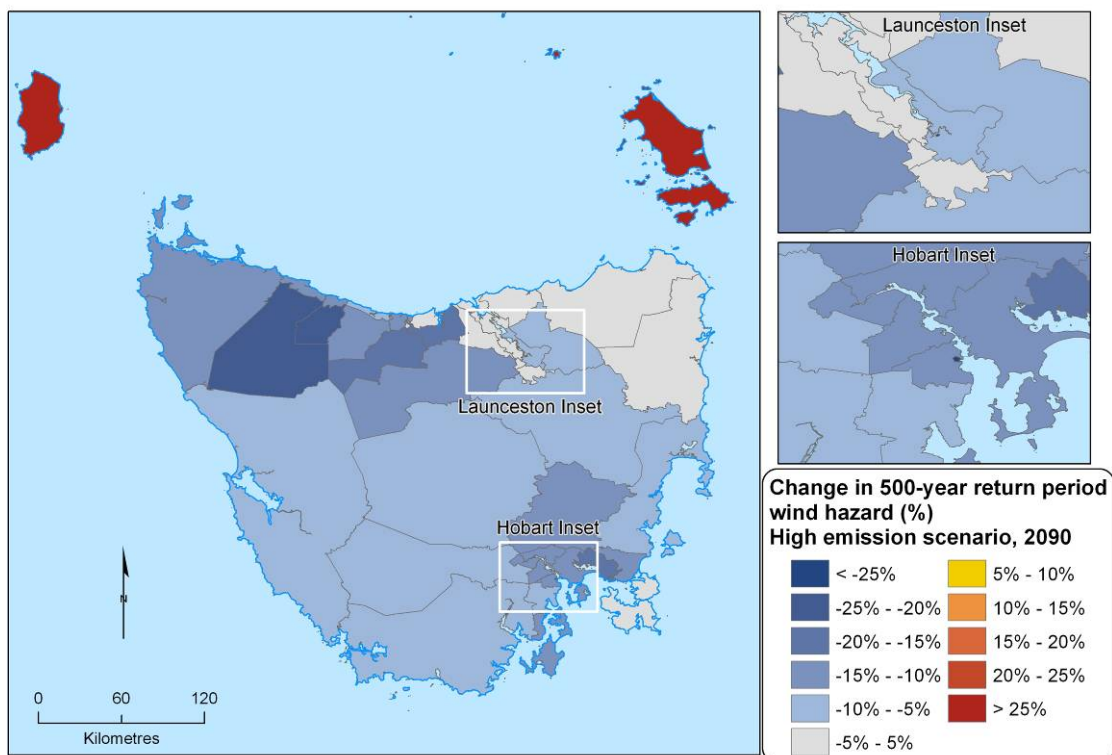
**Figure 47.** Change in local (site) wind hazard by 2050 (% change in 500 year return period wind speed) for the Tasmanian region considering the B1 low emissions climate change scenario.



**Figure 48.** Change in local (site) wind hazard by 2050 (% change in 500 year return period wind speed) for the Tasmanian region considering the A2 high emissions climate change scenario.



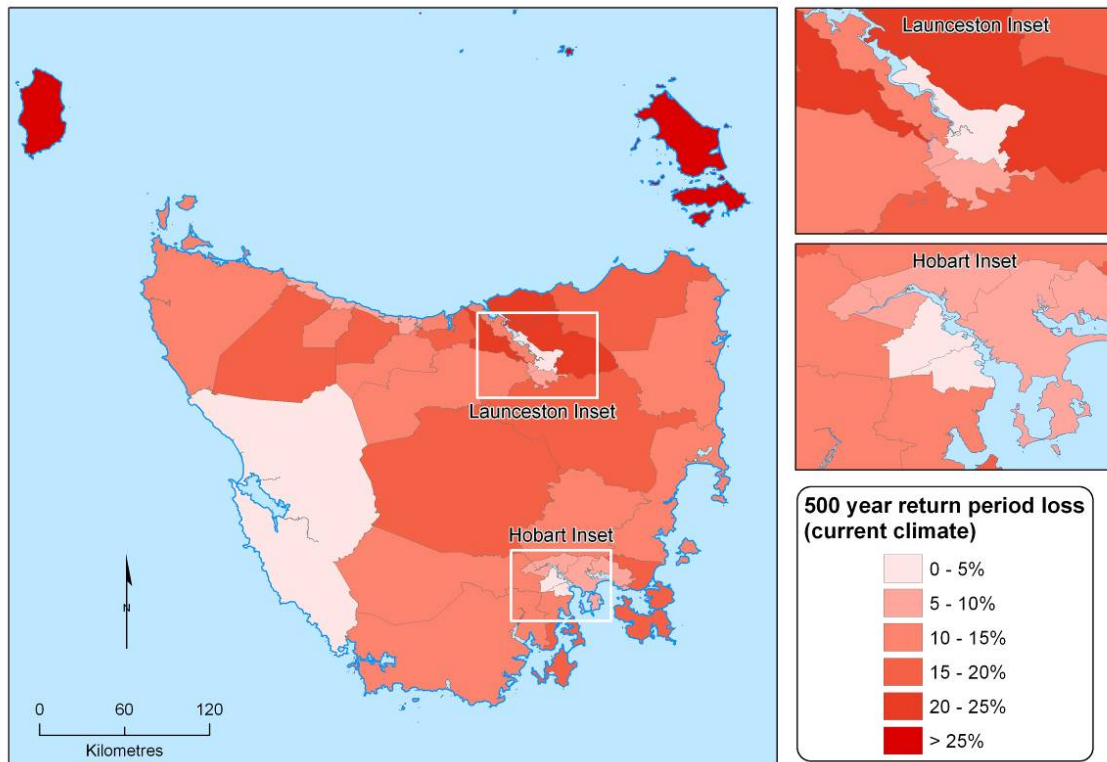
**Figure 49.** Change in local (site) wind hazard by 2090 (% change in 500 year return period wind speed) for the Tasmanian region considering the B1 low emissions climate change scenario.



**Figure 50.** Change in local (site) wind hazard by 2090 (% change in 500 year return period wind speed) for the Tasmanian region considering the A2 high emissions climate change scenario.

## 4.2 WIND RISK

Annualised loss for severe gust winds is in general expressed as the percentage of the total replacement value of the residential structures within each of the 43 SLA's considered in the Tasmanian region. Annualised loss represents the average annual cost to the region due to exposure to the hazard viewed through a very wide window of time; for this study a time window of 2000 years was adopted. [Figure 51](#) presents the loss associated with a 500 year return period (design wind speed) wind hazard event (current climate). The loss is shown as the percentage (%) of the replacement value of the residential building stock over each SLA of the Tasmanian region.

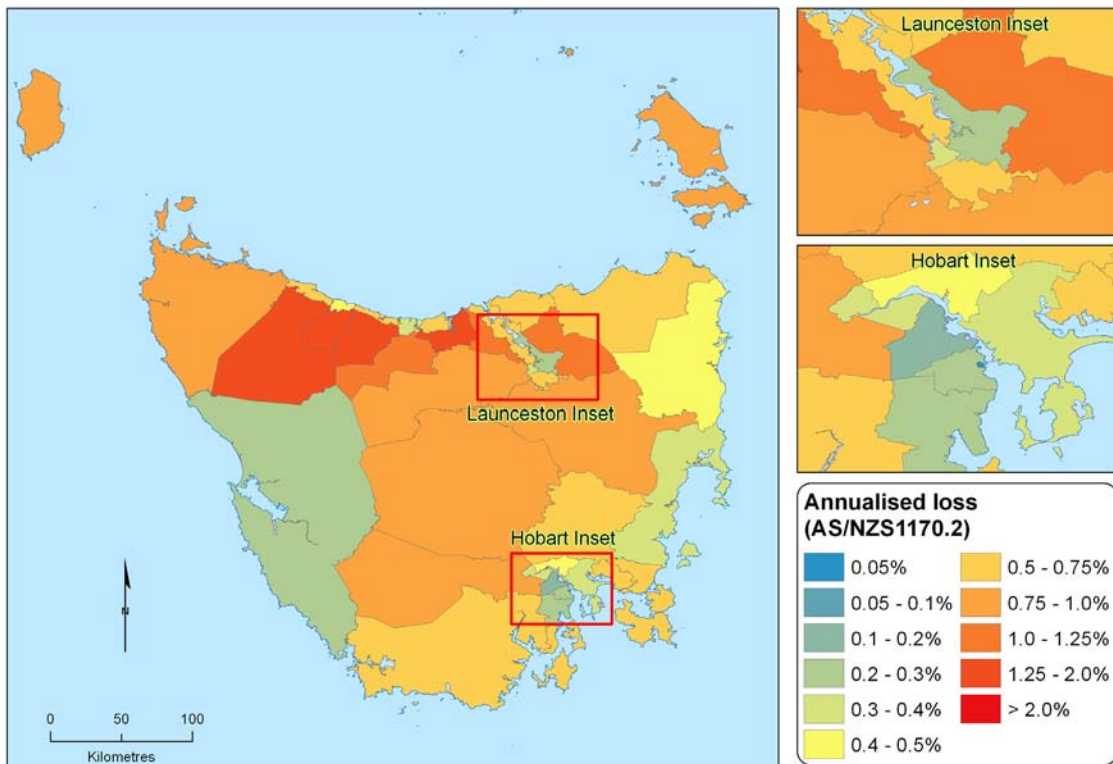


**Figure 51.** Loss (% of the replacement value of the residential building stock) associated with a 500 year return period wind hazard event (AS/NZS 1170.2 hazard) over the Tasmanian region.

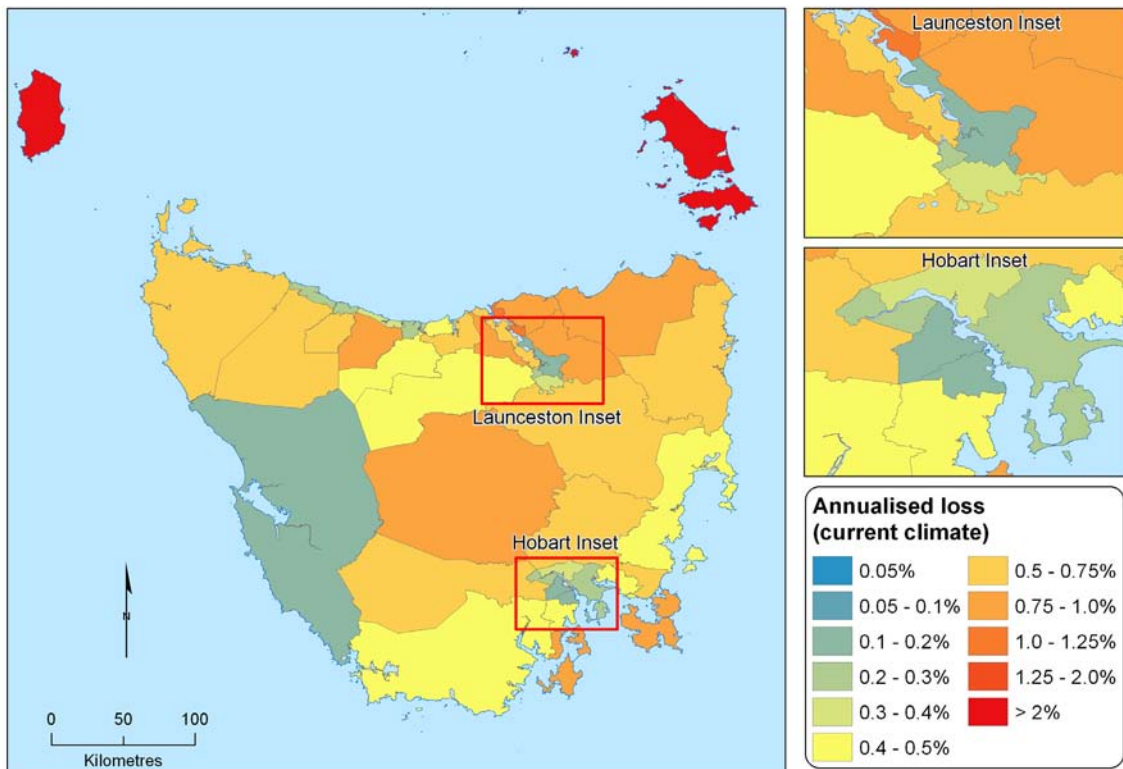
The annualised loss presented in [Figures 52](#) and [53](#) highlight regions most at risk with respect to the hazard in AS/NZS 1170.2 and also the modelled current climate hazard. Regions of high urbanisation such as Hobart, Launceston and the north coast all have a relatively low annualised loss associated with them. [Table 11](#) provides the TOP-15 ranked SLA regions in Tasmania with regards to annualised loss (% replacement cost) from both the AS/NZS 1170.2 proxy hazard and also the modelled current climate severe wind hazard. See [Figure 5](#) for a map of the SLA regions. For each SLA region, [Table 11](#) also includes the

- aggregated building level hazard (local hazard) for the residential building
- percentage (%) of pre-1980 residential buildings
- 2009 value (\$A million) of the residential building.

[Table 12](#) ranks (TOP-15 SLA regions) the gust wind speed hazard for the 43 SLA regions for both the AS/NZS 1170.2 proxy hazard and also the modelled current climate severe wind hazard. The 50-year RP hazard is shown as the more frequent extreme events have a more significant weighting on the annualized loss (see [Figure 62](#)). It should be noted that this is not the average hazard over each SLA regions but the aggregated local wind gust hazard at each of the residential building locations within the SLA region.



**Figure 52.** Annualised Loss (% of the replacement value of the residential building stock) associated with 10 to 2000 year return period wind hazard events (AS/NZS 1170.2 for Tasmania).



**Figure 53.** Annualised Loss (% of the value of the residential building stock) associated with 10 to 2000 year return period modelled wind hazard events (Tasmanian region).



**Table 11.** TOP-15 ranked Tasmanian SLA regions with regards to Annualised Loss (% replacement cost)

(a) sorted Annualised Loss by AS/NZS 1170.2 component hazard.

(b) sorted Annualised Loss by modelled current climate component hazard.

See [Appendix 2](#) for the results for all SLA regions.

(a)

Location (SLA)	2009 value \$A million	% of pre- 1980 structures	Wind Hazard (50 year RP)		Annualised Loss	
			AS/NZS 1170.2 hazard (m/s)	Modelled hazard (m/s)	for AS/NZS 1170.2 hazard	for modelled hazard
Central Coast (M) - Pt B	453	66	38.9	34.4	<b>1.65</b>	0.83
Waratah/Wynyard (M) - Pt B	409	69	37.7	32.9	<b>1.43</b>	0.65
Latrobe (M) - Pt B	105	60	38.0	34.1	<b>1.41</b>	0.74
Burnie (C) - Pt B	272	70	36.8	32.1	<b>1.33</b>	0.61
Kentish (M)	907	60	36.3	31.1	<b>1.17</b>	0.47
West Tamar (M) - Pt B	272	53	36.9	35.6	<b>1.10</b>	0.89
Launceston (C) - Pt C	486	67	35.7	35.1	<b>1.03</b>	0.96
Meander Valley (M) - Pt B	1393	67	33.9	30.1	<b>0.97</b>	0.48
Circular Head (M)	1088	74	33.3	31.1	<b>0.93</b>	0.58
King Island (M)	260	84	32.5	43.8	<b>0.85</b>	3.46
Flinders (M)	148	71	32.8	45.7	<b>0.84</b>	3.67
Central Highlands (M)	876	66	33.9	34.4	<b>0.82</b>	0.89
Derwent Valley (M) - Pt B	425	68	33.6	31.8	<b>0.79</b>	0.54
Northern Midlands (M) - Pt B	729	85	32.4	31.7	<b>0.78</b>	0.70
Sorell (M) - Pt B	168	70	33.8	33.9	<b>0.71</b>	0.72

(b)

Location (SLA)	2009 value \$A million	% of pre- 1980 structures	Wind Hazard (50 year RP)		Annualised Loss	
			AS/NZS 1170.2 hazard (m/s)	Modelled hazard (m/s)	for AS/NZS 1170.2 hazard	for modelled hazard
Flinders (M)	148	71	32.8	45.7	0.84	<b>3.67</b>
King Island (M)	260	84	32.5	43.8	0.85	<b>3.46</b>
George Town (M) - Pt A	645	80	30.4	35.7	0.52	<b>1.15</b>
Launceston (C) - Pt C	486	67	35.7	35.1	1.03	<b>0.96</b>
George Town (M) - Pt B	276	60	31.3	34.6	0.59	<b>0.95</b>
Kingborough (M) - Pt B	567	59	32.5	35.3	0.57	<b>0.93</b>
West Tamar (M) - Pt B	272	53	36.9	35.6	1.10	<b>0.89</b>
Central Highlands (M)	876	66	33.9	34.4	0.82	<b>0.89</b>
Tasman (M)	556	48	32.4	35.1	0.54	<b>0.84</b>
Central Coast (M) - Pt B	453	66	38.9	34.4	1.65	<b>0.83</b>
Dorset (M)	1065	71	30.2	32.0	0.60	<b>0.76</b>
Latrobe (M) - Pt B	105	60	38.0	34.1	1.41	<b>0.74</b>
Sorell (M) - Pt B	168	70	33.8	33.9	0.71	<b>0.72</b>
Break O'Day (M)	1305	54	29.9	32.5	0.45	<b>0.71</b>
Northern Midlands (M) - Pt B	729	85	32.4	31.7	0.78	<b>0.70</b>

**Table 12. TOP-15 ranked Tasmanian SLA regions with regards to local wind hazard**

(a) sorted by 50-year return period AS/NZS 1170.2 hazard (m/s).

(b) sorted by 50-year return period modelled current climate hazard (m/s).

The 50-year RP hazard is shown in the table as the more frequent extreme events have a more significant weighting on the annualized loss.

(a)

Location (SLA)	2009 value \$A million	% of pre-1980 structures	Wind Hazard (50 year RP)		Annualised Loss	
			AS/NZS 1170.2 hazard (m/s)	Modelled hazard (m/s)	for AS/NZS 1170.2 hazard	for modelled hazard
Central Coast (M) - Pt B	453	66	<b>38.9</b>	34.4	1.65	0.83
Latrobe (M) - Pt B	105	60	<b>38.0</b>	34.1	1.41	0.74
Waratah/Wynyard (M) - Pt B	409	69	<b>37.7</b>	32.9	1.43	0.65
West Tamar (M) - Pt B	272	53	<b>36.9</b>	35.6	1.10	0.89
Burnie (C) - Pt B	272	70	<b>36.8</b>	32.1	1.33	0.61
Kentish (M)	907	60	<b>36.3</b>	31.1	1.17	0.47
Launceston (C) - Pt C	486	67	<b>35.7</b>	35.1	1.03	0.96
Sorell (M) - Pt A	1581	53	<b>34.0</b>	31.6	0.65	0.43
Central Highlands (M)	876	66	<b>33.9</b>	34.4	0.82	0.89
Meander Valley (M) - Pt B	1393	67	<b>33.9</b>	30.1	0.97	0.48
Sorell (M) - Pt B	168	70	<b>33.8</b>	33.9	0.71	0.72
Derwent Valley (M) - Pt B	425	68	<b>33.6</b>	31.8	0.79	0.54
Circular Head (M)	1088	74	<b>33.3</b>	31.1	0.93	0.58
Southern Midlands (M)	795	70	<b>32.8</b>	32.3	0.67	0.60
Flinders (M)	148	71	<b>32.8</b>	45.7	0.84	3.67

(b)

Location (SLA)	2009 value \$A million	% of pre-1980 structures	Wind Hazard (50 year RP)		Annualised Loss	
			AS/NZS 1170.2 hazard (m/s)	Modelled hazard (m/s)	for AS/NZS 1170.2 hazard	for modelled hazard
Flinders (M)	148	71	32.8	<b>45.7</b>	0.84	3.67
King Island (M)	260	84	32.5	<b>43.8</b>	0.85	3.46
George Town (M) - Pt A	645	80	30.4	<b>35.7</b>	0.52	1.15
West Tamar (M) - Pt B	272	53	36.9	<b>35.6</b>	1.10	0.89
Kingborough (M) - Pt B	567	59	32.5	<b>35.3</b>	0.57	0.93
Tasman (M)	556	48	32.4	<b>35.1</b>	0.54	0.84
Launceston (C) - Pt C	486	67	35.7	<b>35.1</b>	1.03	0.96
George Town (M) - Pt B	276	60	31.3	<b>34.6</b>	0.59	0.95
Central Highlands (M)	876	66	33.9	<b>34.4</b>	0.82	0.89
Central Coast (M) - Pt B	453	66	38.9	<b>34.4</b>	1.65	0.83
Latrobe (M) - Pt B	105	60	38.0	<b>34.1</b>	1.41	0.74
Sorell (M) - Pt B	168	70	33.8	<b>33.9</b>	0.71	0.72
Waratah/Wynyard (M) - Pt B	409	69	37.7	<b>32.9</b>	1.43	0.65
Break O'Day (M)	1,305	54	29.9	<b>32.5</b>	0.45	0.71
Southern Midlands (M)	795	70	32.8	<b>32.3</b>	0.67	0.60

Table 13 provides a ranking of the TOP-15 SLA regions with regards to the percentage of pre-1980 residential buildings.

**Table 13.** TOP-15 ranked Tasmanian SLA regions with regards to the percentage of residential structures built prior to 1980 (as in 2009 NEXIS database).

Location (SLA)	2009 value \$A million	% of pre-1980 structures	Wind Hazard (50 year RP)		Annualised Loss	
			AS/NZS 1170.2 hazard (m/s)	Modelled hazard (m/s)	for AS/NZS 1170.2 hazard	for modelled hazard
Launceston (C) - Inner	15	<b>100</b>	25.9	24.6	0.14	0.10
West Coast (M)	617	<b>90</b>	27.2	25.2	0.23	0.15
Northern Midlands (M) - Pt B	729	<b>85</b>	32.4	31.7	0.78	0.70
Hobart (C) - Remainder	5170	<b>84</b>	26.9	26.4	0.21	0.19
King Island (M)	260	<b>84</b>	32.5	43.8	0.85	3.46
George Town (M) - Pt A	645	<b>80</b>	30.4	35.7	0.52	1.15
Burnie (C) - Pt A	1634	<b>80</b>	29.4	26.1	0.43	0.21
Launceston (C) - Pt B	6053	<b>77</b>	27.8	26.2	0.29	0.20
Derwent Valley (M) - Pt A	697	<b>75</b>	28.8	27.1	0.35	0.25
Devonport (C)	2615	<b>74</b>	27.9	26.5	0.35	0.24
Glenorchy (C)	4315	<b>74</b>	26.7	26.0	0.20	0.17
Circular Head (M)	1088	<b>74</b>	33.3	31.1	0.93	0.58
Flinders (M)	148	<b>71</b>	32.8	45.7	0.84	3.67
Dorset (M)	1065	<b>71</b>	30.2	32.0	0.60	0.76
Central Coast (M) - Pt A	1877	<b>71</b>	30.1	27.5	0.52	0.32

Considering Table 11, for the AS/NZS 1170.2 based wind hazard (only three airports considered) the highest wind risk areas (annualised loss) are located in the northern part of the state. For the modelled wind hazard the Bass Strait islands have significantly more wind risk than other regions; north coast regions also figure significantly in the modelled rank list of the TOP-15 regions however the magnitude of the risk in general is slightly lower. In general the modelled assessment has lower or similar wind risk values for SLA's outside the Bass Strait islands. Table 12 indicates that the Bass Strait islands have significantly more hazard in the modelled hazard assessment (and wind risk) than for the AS/NZS 1170.2 assessment. The north coast of Tasmania also features prominently in the ranking of wind hazard. There is a more uniform range of hazard for the TOP-15 SLA's assessed with the AS/NZS 1170.2 based hazard compared to the modelled hazard.

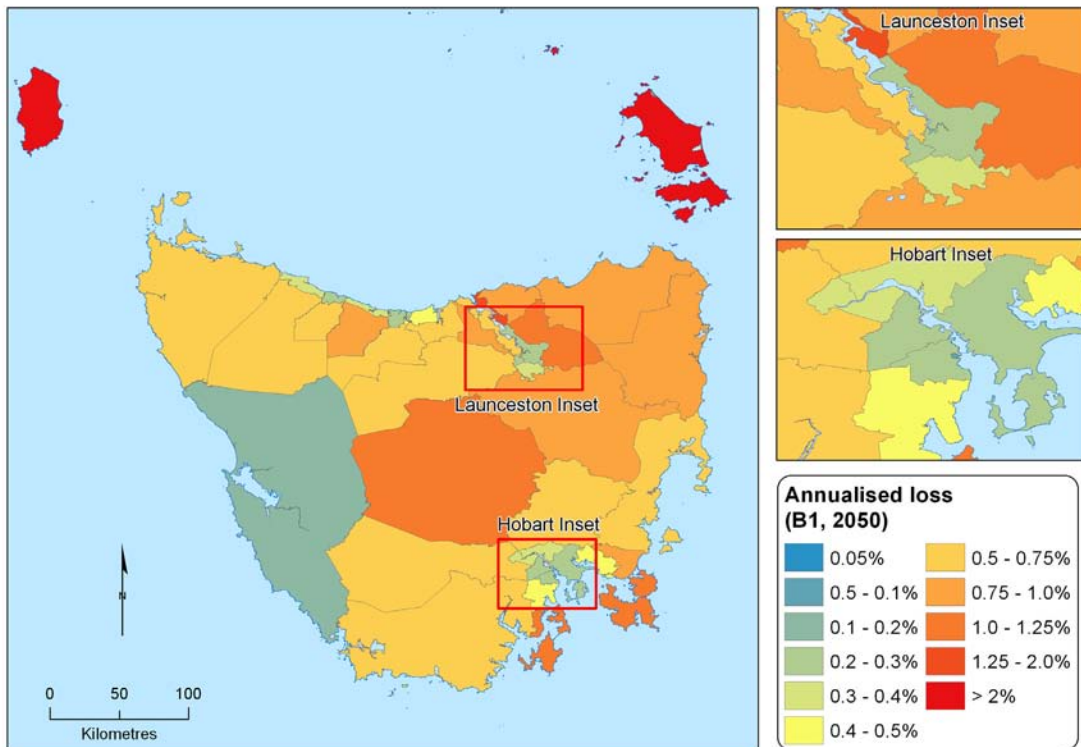
Areas with a high proportion of building stock pre-dating the modern building codes (hence increased vulnerability) and moderate hazard levels also have significant risk levels. These results indicate that the highest levels of risk occur where the hazard is greatest as well as and where the proportion of older structures is high.

Figures 54 and 55 show the annualised loss for the Tasmanian region in 2050 and 2090 when considering the B1 low emission scenario and the ABS Series B population projection (% of the replacement value of the residential building stock). Figure 56 and 57 also show the projected annualised loss however the high emissions A2 scenario is considered in place of the B1 scenario whilst still considering the ABS Series B population projection. All new buildings added to the current building stock (utilising the population projection maintaining the present ratio of people to buildings) are constructed to the current building standards.

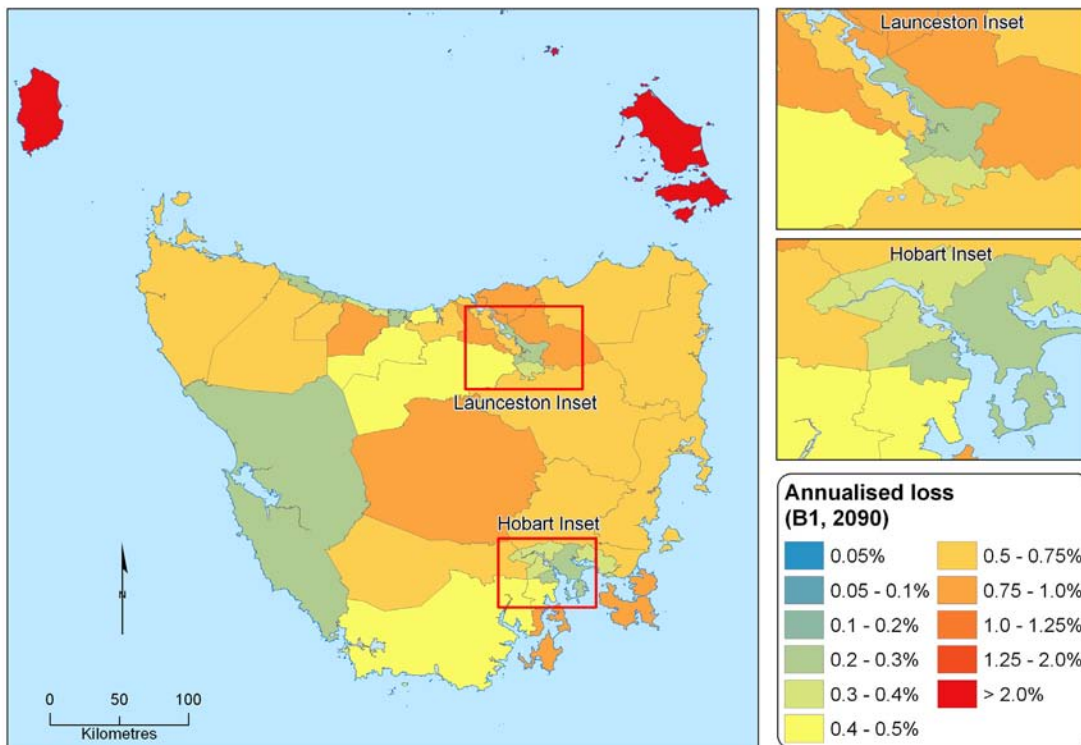
It is difficult to observe the changes in annualised loss (risk) between Figures 52 to 55 in comparison to the current climate risk. We therefore present Figures 54 to 57 as a percentage difference from the current climate risk (shown in Figures 58 to 61). For 2050 (Figure 58 & 59) there is a small difference between the wind risk for the B1 and A2 scenarios, with the A2 scenario being 5 to 10% higher over most of the Tasmanian region. The populated regions, Hobart and the northern coast including Launceston show wind risk increasing by -5 to 10% for the B1 scenario (region specific) and 5 to 20% for the A2 scenario.

For 2090 (Figures 60 & 61) the changes in annualised loss (risk) in comparison to the current climate risk are smaller as the impact of the number of new dwellings introduced by the ABS Series B population projection begins to have an impact (proportion of older structures is reduced within the building population). Although there is a small decrease in the 500-year return period wind speed (see Figures 50 & 51), the wind risk is dominated by events with a return period of up to 50 years. This is illustrated by Figure 63 which aggregates the risk over the whole of the Tasmanian region and shows the contribution to Annualised Loss (%) associated with segments of the return period hazard range. Severe wind events with hazard exceedance levels more frequent than one in 50 years dominate the wind risk, resulting in over 90% of the loss for the Tasmanian region. This is confirmed by the small change in hazard in AS/NZS 1170.2 for Region A (see Table 1) where the range between the 5-year and 2000 year return period hazard is 16 m/s. Contrast this for Region D (experiences tropical cyclone hazard levels) where the hazard range is more than 60 m/s.

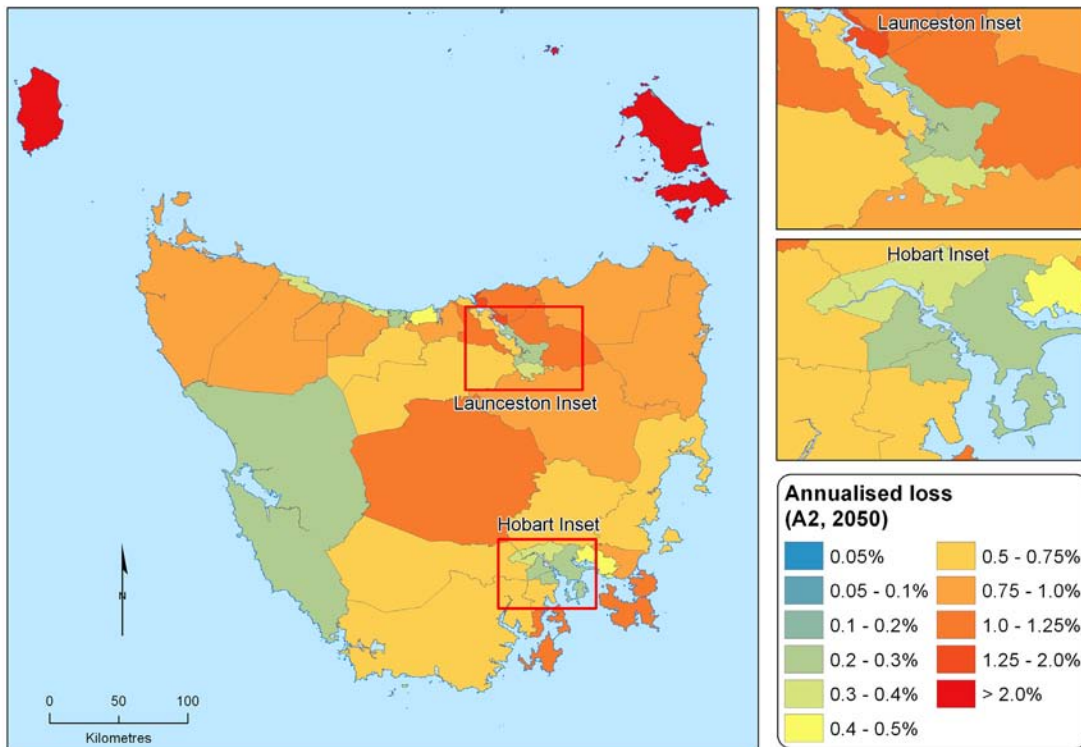
Appendix 2 provides a number of tables which allow the reader to examine the wind risk (expressed as the % of the replacement value of the residential building stock) for each of the Tasmanian SLA (Statistical Local Area) regions. Shown are the current climate risk, utilising both the modelled (C20C) hazard and the Australia – New Zealand Wind Loadings Standard (AS/NZS 1170.2, 2011), as well as the future wind risk for time intervals (2020 – 2090), three population projections (Series A, B & C) and two climate change greenhouse gas scenarios (A2 & B1).



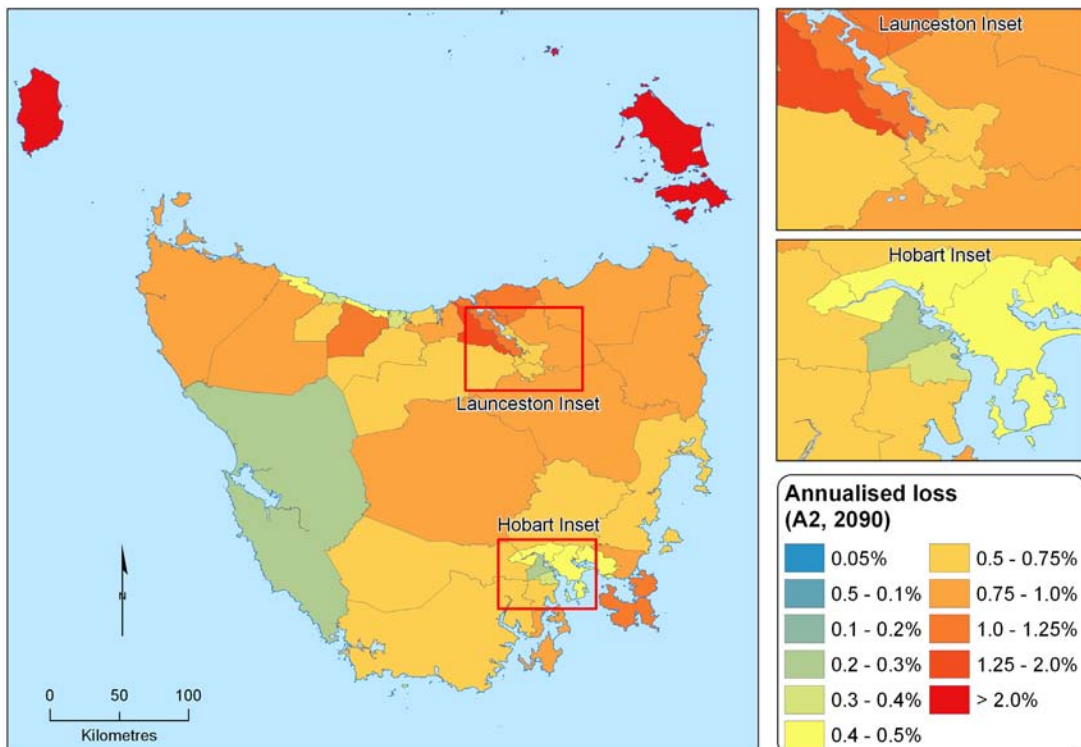
**Figure 54.** Annualised Loss (% of the value of the residential building stock) associated with 10 to 2000 year return period modelled wind hazard events (2050 for B1 low emission scenario & ABS Series B population projection).



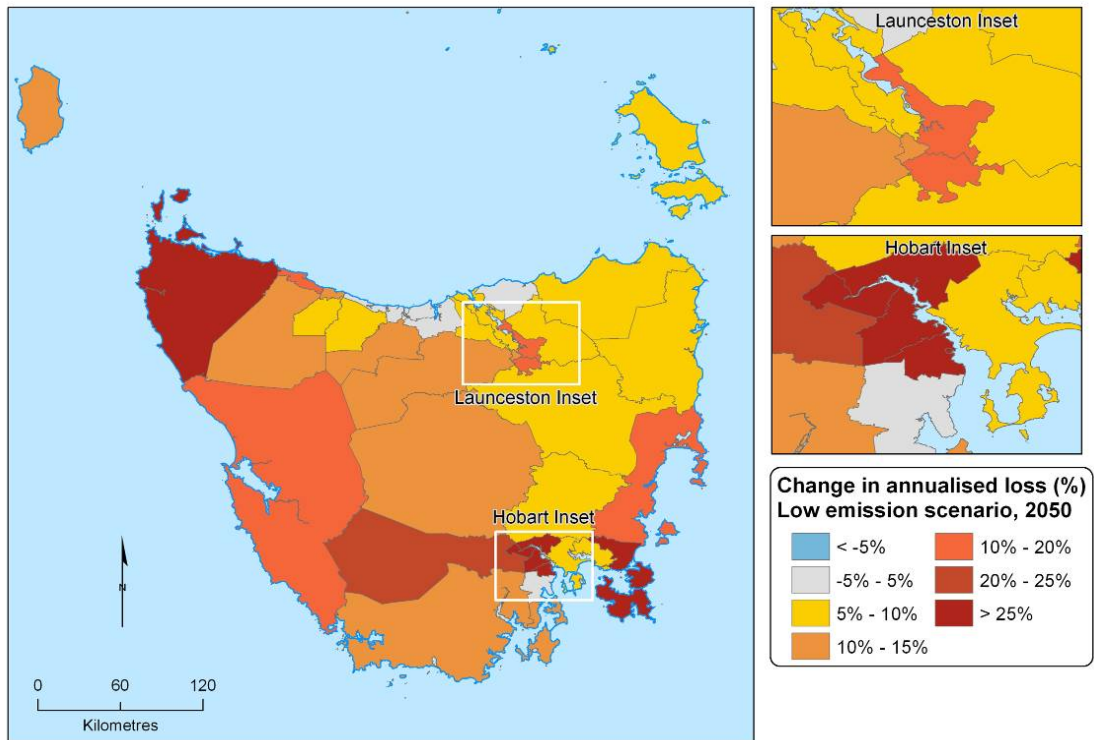
**Figure 55.** Annualised Loss (% of the value of the residential building stock) associated with 10 to 2000 year return period modelled wind hazard events (2090 for B1 low emissions scenario & ABS Series B population projection).



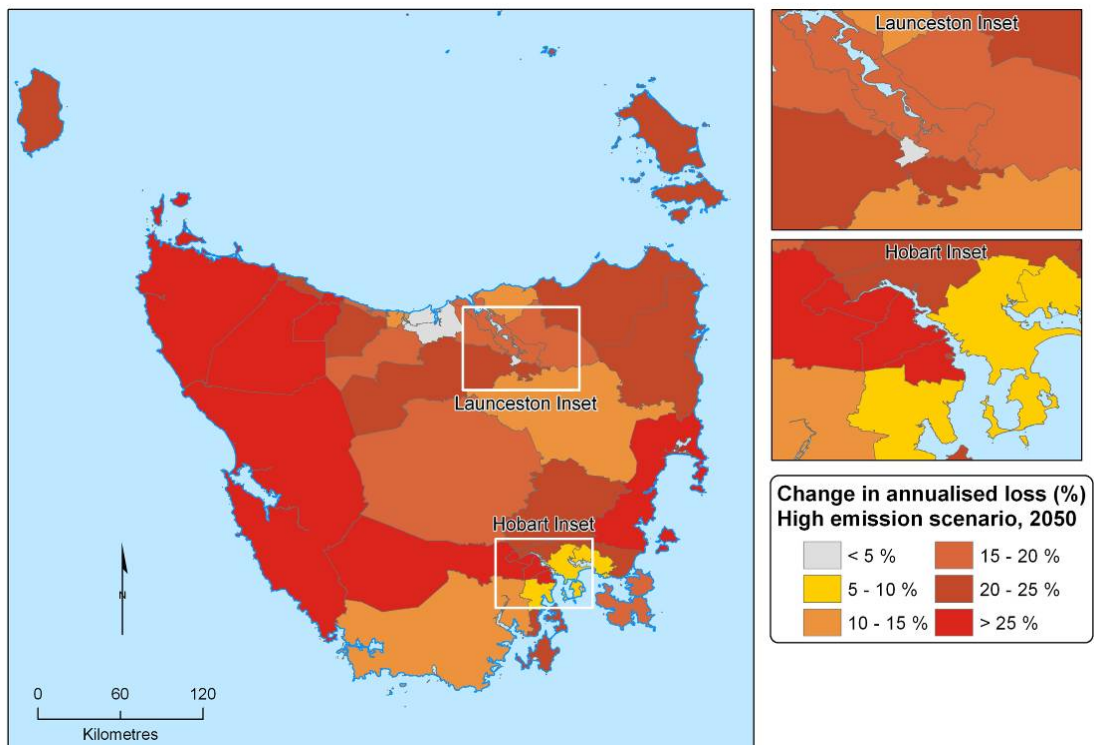
**Figure 56.** Annualised Loss (% of the value of the residential building stock) associated with 10 to 2000 year return period modelled wind hazard events (2050 for A2 high emissions scenario & ABS Series B population projection).



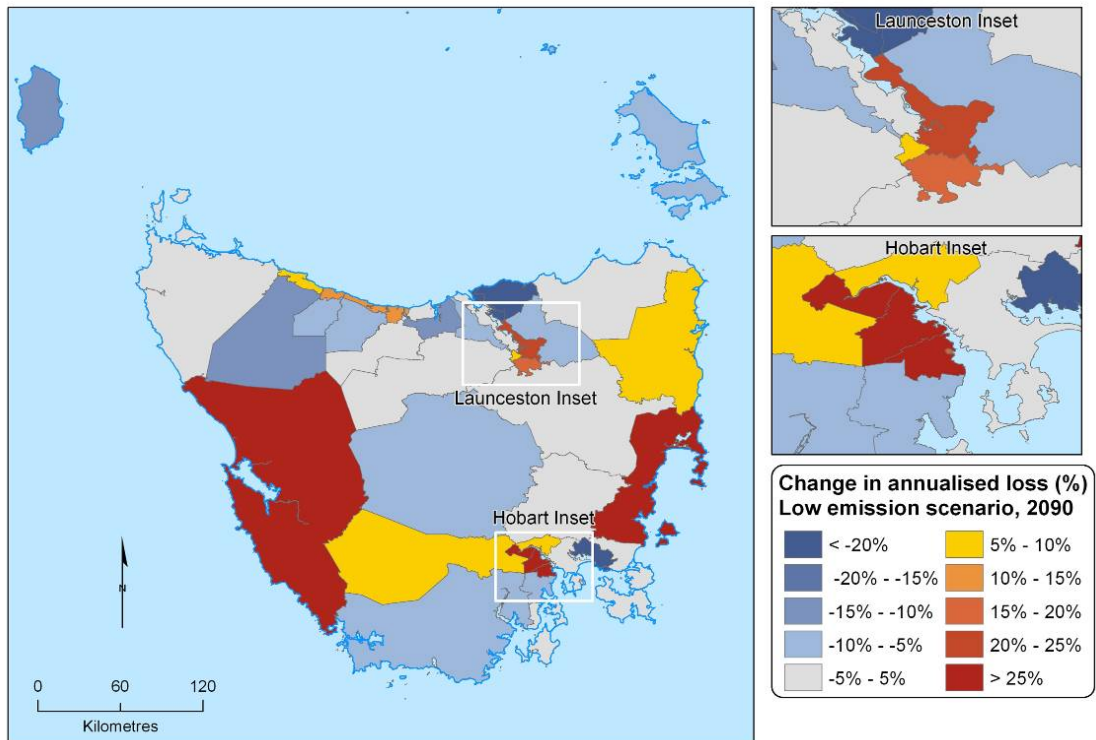
**Figure 57.** Annualised Loss (% of the value of the residential building stock) associated with 10 to 2000 year return period modelled wind hazard events (2090 for A2 high emissions scenario & ABS Series B population projection).



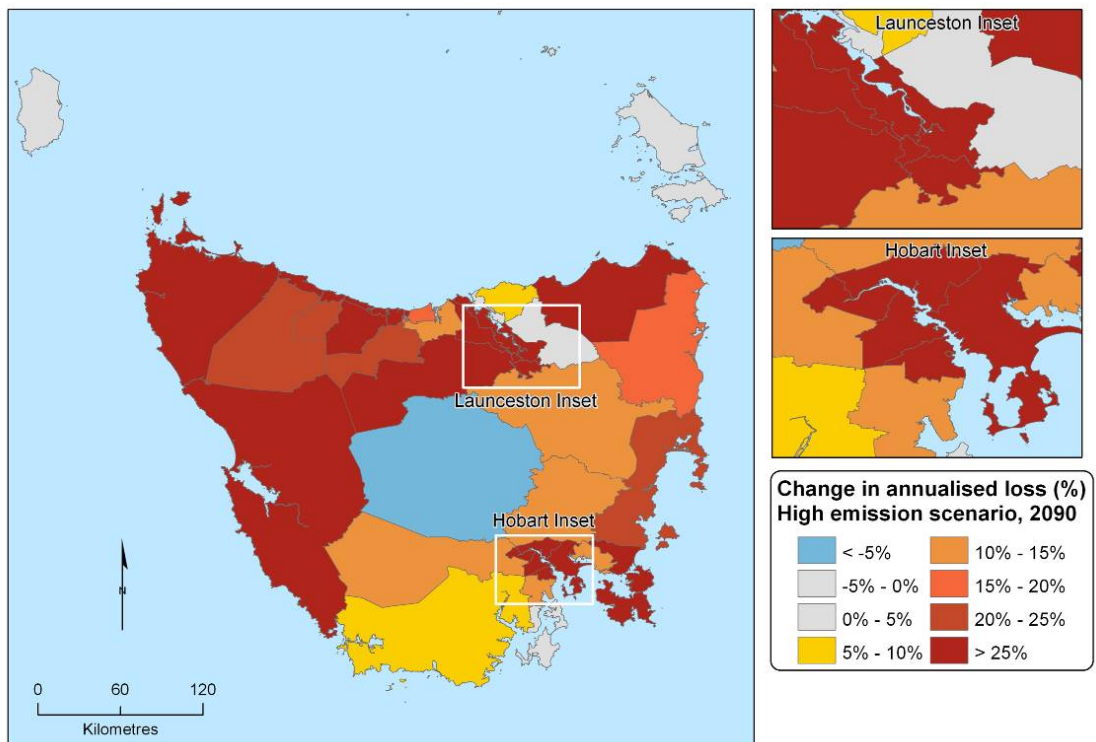
**Figure 58.** Change in Annualised Loss (%) associated with 10 to 2000 year return period modelled wind hazard events (2050 for B1 low emissions scenario & ABS Series B population projection).



**Figure 59.** Change in Annualised Loss (%) associated with 10 to 2000 year return period modelled wind hazard events (2050 for A2 high emissions scenario & ABS Series B population projection).

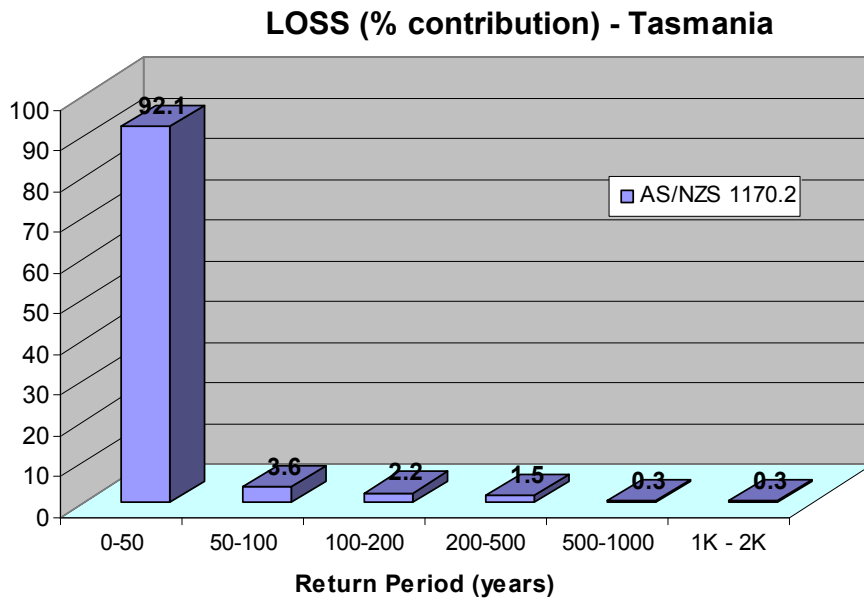


**Figure 60.** Change in Annualised Loss (%) associated with 10 to 2000 year return period modelled wind hazard events (2090 for B1 low emissions scenario & ABS Series B population projection).



**Figure 61.** Change in Annualised Loss (%) associated with 10 to 2000 year return period modelled wind hazard events (2090 for A2 high emissions scenario & ABS Series B population projection).





**Figure 62.** Contribution to Annualised Loss (%) associated with segments of the return period hazard for the whole of the Tasmanian region. Severe wind events with hazard exceedance levels more frequent than one in 50 years dominate the risk spectrum (hazard utilised here is AS/NZS 1170.2 (2011) but results are similar for all hazard maps considered within this report).

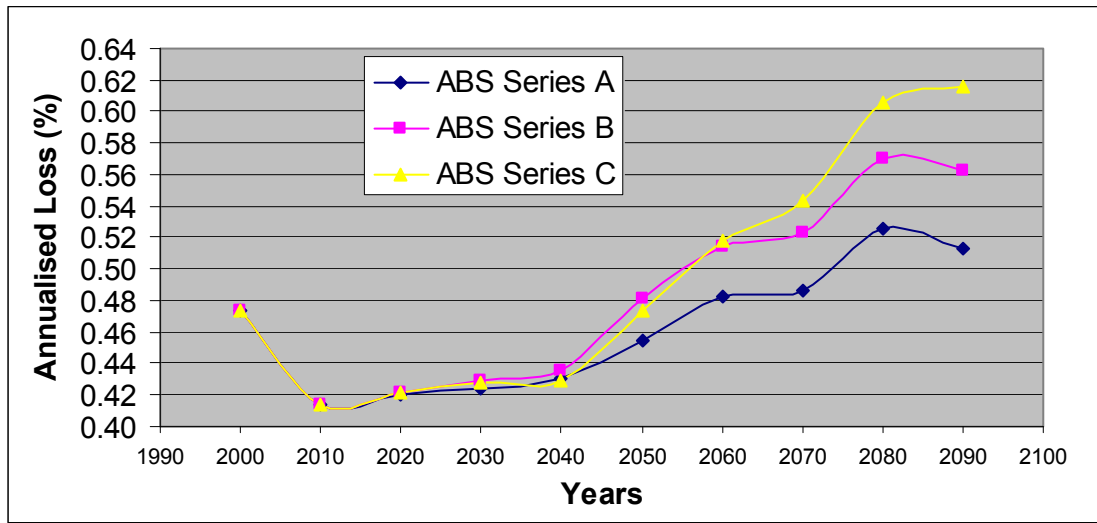


Figure 63. Annualised Loss (%) for A2 scenario associated with the three ABS population projections (Series A, B & C) for the whole of the Tasmanian region.

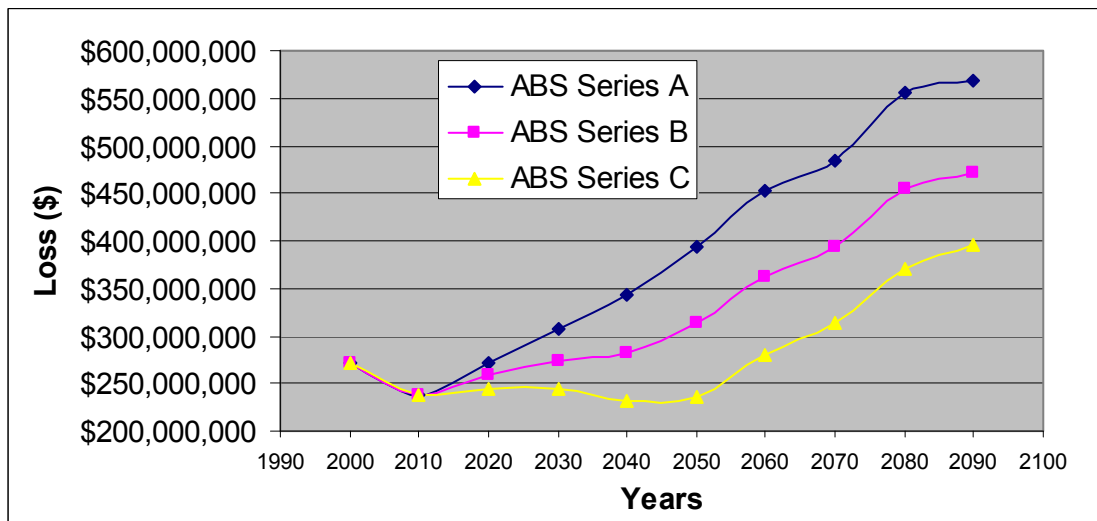


Figure 64. Annualised Loss (\$) for A2 scenario associated with the three ABS population projections (Series A, B & C) for the whole of the Tasmanian region.

Figures 63 and 64 show the 21<sup>st</sup> century Annualised Loss (both as a % and in \$A) for the whole of the Tasmanian region associated with the A2 climate change scenario and the three ABS population projections (Series A, B & C). Notice from Figure 64 that the Series A projection, which is associated with higher population growth, results in a lower annualised loss (%) towards the end of the 21<sup>st</sup> century due to the lower percentage of legacy residential housing amongst the combined existing and new-builds within the building stock. The series A projection also results in the higher annualised loss (\$) towards the end of the 21<sup>st</sup> century (Figure 65) due to the larger number of residential buildings associated with the higher population (i.e. the loss per building aggregates to a higher value for a larger number of buildings).

### 4.3 WIND RELATED CASUALTIES AND DEATHS – CURRENT CLIMATE

For current climate, an assessment of possible casualties and deaths associated with severe wind events was conducted for the Hobart region. As there is little change in hazard for the Hobart region for the climate change scenarios considered, the analysis has not been repeated for future climate.

The casualty model used to estimate the number of people with various levels of injury and mortality was based on the NHEMATIS casualty model (ESSA, 1999) derived from United States injury and mortality data. Injury level classifications for the model are detailed in Table 14, and the probabilities for each classification are presented in Table 15. Documentation from the experience of emergency services indicates that both damaged and severely damaged homes can injure occupants sheltering inside. People are also vulnerable to injury from wind-borne debris. While some people do get caught outside when a storm affects their community, casualties from wind-borne debris are generally small as the majority of the affected population will shelter (in their homes or in other shelter) during the passage of the storm. For this reason, we have not calculated the casualty figures associated with wind-borne debris.

As the severity of an event increases, casualties associated with the evacuation process will increase approximately exponentially. Attempts to rescue stranded people will, in some instances fail, and in addition the stress of the event may precipitate heart attacks and strokes in the elderly or infirm. Despite this, emergency services indicate that *evacuation process casualties* are small, and therefore this component was also not included in the figures calculated.

**Table 14.** Injury level classifications for the NHEMATIS casualty model

INJURY SEVERITY LEVEL	INJURY DESCRIPTION
Minor Injury Severity 1	Injuries requiring basic medical aid without requiring hospitalisation. These types of injuries would require bandages or observation. Some examples are: a sprain, a severe cut requiring stitches, a bump on the head without loss of consciousness.
Moderate Injury Severity 2	Injuries requiring a greater degree of medical care and use of medical technology such as x-rays or surgery, but not expected to progress to a life threatening status. Some examples are: a bump on the head that causes loss of consciousness, fractured bone, dehydration or exposure.
Severe Injury Severity 3	Injuries that pose an immediate life threatening condition if not treated adequately and expeditiously. Some examples are: uncontrolled bleeding, punctured organ, other internal injuries, spinal column injuries, or crush syndrome.
Fatal Severity 4	Instantaneously killed or mortally injured

**Table 15.** Casualty probabilities for wind storms (NHEMATIS casualty model)

PERCENTAGE BUILDING DAMAGE (%)	PROBABILITY OF INJURY STATE				
	UNHARMED	MINOR INJURY	MODERATE INJURY	SEVERE INJURY	FATAL
0.0	1.0	0.0	0.0	0.0	0.0
0.5	0.9999645	0.00003	0.000004	0.0000005	0.000001
5.0	0.999645	0.0003	0.00004	0.000005	0.00001
20.0	0.99645	0.003	0.0004	0.00005	0.0001
45.0	0.9645	0.03	0.004	0.0005	0.001
80.0	0.645	0.3	0.04	0.005	0.01
100.0	0.0	0.4	0.3	0.1	0.2

The injury and mortality (number of people) for the casualty model utilised are shown in Tables 16 & 17 for the Hobart region. The results presented in these two tables depict the injury (Table 16)

associated with the design wind speed (500 year return-period wind gust hazard event) and also the annualised injury (Table 17) associated with a hazard level over the whole region ranging from a 10 year return-period to 2000 year return-period. The annualized injury assumes zero injury for a 10 year return-period hazard over the whole region. These impacts are based on the NHEMATIS casualty model and the injury level classifications and probabilities for each classification detailed in Tables 14 & 15.

**Table 16.** No. of people with injury for the Hobart region (500 yr return-period event).

REGION	POPULATION	SLA <sup>N</sup>	UNHARMED	MINOR	MODERATE	SEVERE	FATAL
HOBART	226753	8	226378.48	316.50	42.20	5.27	10.55

**Table 17.** No. of people with injury for the Hobart region (Annualised).

*The population within eight (8) statistical local areas (SLA's) was considered.*

REGION	POP <sup>N</sup>	SLA <sup>N</sup>	MINOR	MODERATE	SEVERE	FATAL
HOBART	226753	8	5.86	0.79	0.14	0.22

The injury and fatality results are also depicted as the annualised injuries associated with severe wind events ranging from a 10 year return-period hazard to 2000 year return-period hazard (Table 18). In a similar manner to the building losses, the annualised injury assumes no injuries occur for a 10 year return-period gust wind hazard event.

**Table 18.** Annualised casualties for the Hobart region.

REGION	POPULATION	MINOR	MODERATE	SEVERE	FATAL
HOBART	226753	6	1	<1	<1

As indicated in Section 2: methodology – assumptions, this analysis has been undertaken utilising a statistical approach where return- period hazard maps (i.e. hazard over the whole region is equivalent to return-period for a single probability such as 1 in 100 years) have been used as a proxy for actual severe wind events. These extreme events tend to have limited regional impacts (i.e. a severe thunderstorm in the Tasmanian region rarely affects an urban area with greater than 100 dwellings). For considering fatalities and casualties, here we have used the same hazard level over the whole area being considered whereas in reality that hazard level would only affect a reduced area. The results can best be thought of as the aggregation of a large number of events of the same hazard level of a wide period of time, or, in terms of annualised loss, the aggregation over space, time and a range of hazard levels over all return-periods.

## 5. Discussion

Society's vulnerability to extreme weather events increases when urbanization and infrastructure development do not consider local hazards; extreme events and their changing nature. The resulting damage can reach into the billions of dollars, with costs being borne by society through government aid (relief arrangements), emergency management, taxes or levies, or insurance fees. This study has undertaken an evaluation of wind hazard and risk for the Tasmanian region under current and future climate in an effort to provide the underpinning information required to assess the adequacy of current measures in place to protect residential housing (under both current climate and future climate influences).

Failure of a building to withstand wind loads can be catastrophic; building codes require that structures be designed so that the risk from wind hazards is acceptable by community standards. Residential structures are typically designed to have an acceptably low probability of failure over their lifetime (survive 500-year return period severe wind gusts). The 500 year return period wind refers to the strongest wind gust expected to be reached or exceeded in 500 years, on average, or the wind speed with a 1 in 500 chance of being met or exceeded in any one year. Over the design life of a residential building (50 years), there is a 10% chance of this wind speed being exceeded.

We utilised the wind loading standard (AS/NZS 1170.2) as the hazard for the “current climate” wind risk assessment, as the hazard in the Standard underpins the Building Code of Australia (BCA). The BCA utilises the different hazard levels over the Australian continent in an effort to equalise the risk between the low and high hazard regions. Using the wind loading standard as a proxy for actual wind hazard results in an over-estimate of the wind risk, as the standard is a conservative estimate of the actual hazard. The current climate modelled hazard in general provides reduced hazard levels to AS/NZS 1170.2 (see [Figure 41](#) for a comparison of the 500 year return period hazard). There are however regional differences. The regional texture of the hazard provides a first assessment of where the hazard is greatest over the Tasmanian region. This study has built up an improved understanding of wind hazard for Tasmania by utilising downscaled climate model information forced by reanalyses of the later part of the 20<sup>th</sup> century. Two scenarios for future climate hazard have been explored by downscaling six IPCC models (21<sup>st</sup> century for B1 and A2 greenhouse gas scenarios).

The methodology detailed in this report has provided the first ever “buildings-level” assessment of wind risk to residential housing in the Tasmanian region. This wind risk assessment should only be considered as a preliminary assessment of the severe wind risk to residential housing in the Tasmanian region. The combination of a detailed exposure dataset (NEXIS residential database) and detailed wind vulnerability relationships for residential structures (heuristic vulnerability curve development) has been implemented here and represents best-practice with regards to wind risk assessment. This understanding of wind risk will in future be further refined by validating the estimates against insurance industry data (claims).

### *Synoptic hazard*

For the majority of the state of Tasmania, the return period wind speeds are well estimated by utilising the climate model output. The ensemble mean of the simulations indicates that higher hazard levels occur over coastal and elevated regions, and over the Bass Strait islands. There is significant spatial variability reflecting the hazard over elevated terrain. For this elevated terrain the return wind gust speeds are increased relative to the wind hazard over the lower valley regions, supported by the detailed studies of the effect of mountain slopes on wind speeds (Holmes 2007).

### *Thunderstorm hazard*

The results of the thunderstorm analysis are indicative of the spatial pattern of the distribution of thunder-days presented in [Figure 29](#). While there is little spatial texture to the thunderstorm wind hazard map for the Tasmanian region, this resulting hazard map resembles the distribution of

thunder-days with increased hazard across the western and northeastern regions. As expected from an analysis of the observations, it is evident that return period wind speeds from thunderstorms are lower than that from synoptic storms for the majority of the return-period spectrum across most of Tasmania. At high return-periods, severe thunderstorm gusts are stronger than synoptic gusts, however these events tend to be rare and localised (i.e. in general affecting less than 100 structures for a severe thunderstorm event).

**Combined hazard**

Figure 41 presents the difference between the revised estimate of 500-year return period gust wind speed and the existing regional wind speeds specified in the Standard. A large majority of the Tasmanian region is below the hazard level specified in AS/NZS 1170.2. This is to be expected because of the conservative nature of the wind loading standard as an estimate of the actual hazard. This gives confidence that the initial thunderstorm and synoptic wind hazard estimates are reasonably robust.

**Key contributing factors driving wind risk**

The wind risk results indicate that the highest levels of risk occur where the hazard is greatest, and that the level of risk is significantly influenced by the number of older structures (built prior to the implementation of the current building codes) within the local building stock. The key factors driving *current- climate* wind risk with regards to residential structures are:

- the wind hazard;
- the wind vulnerability of the residential structures;
- a tendency to build new structures in higher hazard regions. As a % of total new built residences, there is a tendency to build in higher hazard regions (i.e. higher N number) as shown in Table 19 (see N3 & N4 new builds as a % of total new builds; 14% in period 1946-79, 26% in period 1980-94 and 34% since 1994).

**Table 19.** Hobart residential house distribution against site wind hazard classification (according to AS4055, 2006)

Period	N1	N2	N3	N4	N5	N6	Total
Pre 1914	3048	1447	295	16	0	0	4806
1914-1945	3867	2005	473	18	2	0	6365
1946-1979	18981	9020	4148	517	30	0	32696
1980-1994	5621	4240	2892	526	42	0	13321
Post 1994	1957	2019	1679	371	41	0	6067
Total	33474	18731	9487	1448	115	0	63255

High annualised loss results from either a high hazard or high vulnerability (% older structures), or the combination of both. Annualised loss is significantly higher in tropical coastal regions compared to the Tasmanian region, and the communities there are aware of the elevated risk which is mainly attributable to the high return period (low frequency ) events. The key factors driving *future- climate* wind risk in the Tasmanian region with regards to residential structures are the legacy building stock and increased exposure in existing high hazard regions (predominantly coastal regions).

The legacy building stock, particularly housing built prior to the present building standards, has a significantly greater risk compared to recent construction. The proportion of legacy buildings decreases into the future resulting in decreased risk where hazard levels are maintained during the 21<sup>st</sup> century. Increased exposure particularly in regions which are subjected to high hazard levels

(coastal and some elevated regions) is another key factor driving future wind risk. The community and government are left to consider whether the risk levels are acceptable.

### ***Limitations of the methodology***

The risk assessment process contains a significant number of assumptions which pose limitations on the use of the derived information. There are a range of issues associated with the modelled hazard and computational methodology as well as issues surrounding climate and population projections. These are discussed below under the heading for each component of the risk assessment paradigm.

#### ***Hazard***

The hazard modelling methodology is an emerging science which requires further research for the components of wind hazard. There are major concerns over the intensity and spatial nature of thunderstorms as they have a small impact footprint and their frequency tends to be reduced over the flat plains/valley regions where all Tasmanian airports are located (maximum over elevated regions as the mountains act as a trigger for thunderstorm development). The completeness of input datasets for all wind hazard types is also of concern. For synoptic winds, the changes in the large-scale mean wind speed depicted in [Figure 2](#) has not been replicated in the downscaled fine-resolution modelling. From observations we have utilised the same turbulent intensity (mean wind speed to gust wind speed ratio) for future projections, and we are uncertain of how a changing climate will affect this parameter and its variation with Australia's regional weather patterns (i.e. the frequency and magnitude of extreme synoptic wind events). Much is uncertain about wind behaviour (turbulence) and the consequent impact mechanisms.

#### ***Exposure***

The majority of the information utilised in the NEXIS residential database was obtained from the Tasmanian Valuer-Generals office. This was an excellent dataset however there were issues with completeness with regards to building age and type. Where these attributes were not available, they were derived by examining nearest neighbour attributes in association with a simple rule-set.

Future exposure projections utilising population growth are treated in a simplistic manner. The number of residents per dwelling is maintained as a constant throughout the 21<sup>st</sup> century and there is no expansion of the current urban footprint (i.e. the increased population is contained in the current urban area. In addition, we maintain all existing buildings (legacy building stock) at their current level of vulnerability (i.e. we have not taken into account the level of building renewal, known as knockdown-rebuild, nor the deterioration or level of renovation within the building stock). All new buildings constructed during the 21<sup>st</sup> century are assumed to be built to the current building standards.

#### ***Population Projections***

Using ABS population projections at the small area level assumes that population growth rates are uniform across the states and territories of Australia. This means the population growth rate that is allocated to rural areas or smaller regional centres, which traditionally have stable or even declining populations, is the same as the rate applied to high growth coastal and urban fringe regions. Therefore regional areas tend to be over-estimated and urban fringe areas under-estimated. There are difficulties in calculating projections for small areas using national level models, particularly in relation to estimating migration internally.

Tasmania produces population estimates for their own purposes using models developed locally. The population growth is distributed based on data such as historical shares of growth and information of planned developments. State-based population estimates are usually available at the Statistical Local Area (SLA) and Statistical Division (SD) level of geography, scales fine enough for detailed analysis. However these projections are usually only calculated for about a 20 year time frame.

Geoscience Australia has commenced a project investigating spatial population projections funded by Department of Climate Change and Energy Efficiency. The project aims to build a model for population projections that can be primed with local area development data to produce a map of the projected population. Early investigations are using state-produced population projections to estimate the distribution of the ABS broad area population projections. Alternatively historical proportions of growth rates at the small area level may be used to distribute the ABS population projections. This latter method is simpler and can be applied consistently using national datasets, but may not reflect local knowledge built into state-produced models. Both methods are likely to estimate the small area population more reliably than using the ABS projections utilised in this study. When available, it will be possible to use this population projection data for updating this wind risk assessment.

#### *Vulnerability*

The extensive vulnerability relationships (utilising a heuristic knowledge-based approach) provide an improved understanding of residential housing damage associated with gust wind speeds. However, independent validation against insurance data for a range of events should be undertaken to fully assess the utility of the vulnerability curves as well as quantifying uncertainties associated with their application. Validation against insurance data would also assist in obtaining a better understanding of the losses associated with non-structural damage (such as contents, fencing, garden sheds etc.) as well as quantifying the post-disaster inflation costs (scarcity of labour and materials) associated with major events particularly in more remote locations.

For future building vulnerability, we assume no changes to construction methods or to regional wind classifications. We maintain the building's structural strength at its current level, not accounting for deterioration and lack of maintenance, or for that matter improvements brought about by renovations and retrofitting to structures of improved building practices.

#### *Risk*

This study currently only considers structural losses with regards to residential housing. It does not consider losses associated with items attached to residential buildings (such as porches, pergolas, decks), nor losses associated with damage to sheds, out-housing and fencing. Damage associated with water ingress into damaged structures (wind driven rain) affecting contents as well as fittings is also not considered. Insurance industry experiences indicate this can be between 50 and 100% of the structural losses, depending on the economic circumstances of the home-owners. Indirect losses are also not considered. These are associated with productivity, business disruption, emergency management and medical costs as well as environmental and agricultural damage.

Direct losses caused by tree blow-down (debris such as branches and trunks) have been brought to our attention by the insurance industry as they account for a significant portion of damage in the older established areas. Hazard events well below the residential housing design wind speed level can cause significant tree debris resulting in damage to properties. This is particularly prevalent in established suburbs with mature trees and certain types of trees are known to be more susceptible particularly after a drought period. Tree damage has not been considered in this analysis, but with ground-based and satellite remote sensing been employed to quantify vegetation associated with the electricity distribution network, the technique described here may be relevant to another application. All direct loss considered is in terms of replacement value. There can be a significant difference in the actual value and replacement value for the older segment of the building stock. It may be possible in the future to develop an understanding of the relationship between actual and replacement value for a range of residential structural types and/or to access residential rates valuations for this determination.

The study utilises a statistical approach where return period hazard maps are informing the probable maximum loss (PML) curves generated for each region. The statistical approach does not model actual events, which tend to have limited regional impacts (i.e. a severe thunderstorm in the



Tasmanian region rarely affects an urban area with greater than 100 dwellings). Parallel earthquake risk research comparing statistical and event-based approaches (Patchett *et al.* 2005) has indicated that statistically defined hazard yields higher assessments of risk than those from natural hazard event based simulations. Consequently, the PML curves developed here are considered conservative compared to those that would be derived utilising an event-based approach, and the risk assessment resulting should also be considered as being conservative.

***Broad strategies for the mitigation of wind risk***

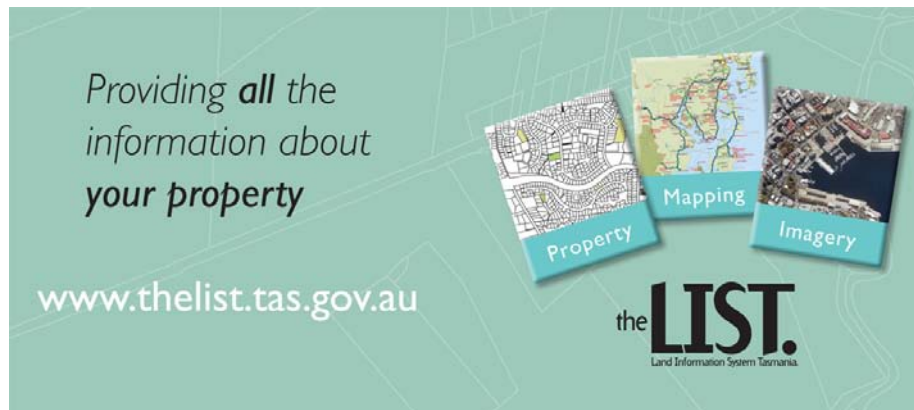
Discussions regarding the mitigation of wind risk (within the current climate context) tend to focus on issues of wind vulnerability reduction and compliance with regards to the building code. The outputs/products and the extension of the information are discussed in the next sub-section.

This study has aimed to lay the foundation and provide the underpinning information that is required for the exploration of adaptation strategies. The results suggest that much of the Tasmanian region will be well serviced by the current building code to the end of the 20<sup>th</sup> century. Many of the wind hazard and risk results are presented in terms of percentage change from current (baseline) conditions. Often, people understand these concepts with little difficulty, and an intuitive grasp of the results can improve the willingness of government, managers and the public to include this information in future discussions and plans.

Demonstrating the ability of more accessible formats to easily convey technical information to decision makers and the public is an important step in bridging the gap between science and policy. Broad consultation within Government and with infrastructure managers will generate potential policy actions to initiate change for communities or service providers who are particularly vulnerable to extreme weather events (regional context). Understanding how our regional climate (and the extremes associated with it) will change over the coming decades is a vital step towards effective local adaptation (where required). Successful strategies for reducing risk associated with severe wind storms will depend on effective communication of problems and solutions to responsible decision makers. If practitioners understand the science driving adaptation strategies, they will be more engaged and better solutions will be the result.

Issues such as retrofitting residential structures to reduce their vulnerability (legacy buildings not built to the current building standard), materials deterioration and also undertaking regular building surveys (say every 5 years) need to be considered. Some consider it strange that we have roadworthy certificates on motor vehicles however regular surveys for our most expensive asset (house assessments focused on structural, aesthetic and energy issues) are only compulsory in the A.C.T. at the point of sale. Surveys particularly focusing on older structures, investigating their vulnerability and presenting/discussing adaptation options (if applicable), would be a valuable community service particularly as these older homes may cause a threat to their neighbours (becoming debris following structural failure).

*Wind hazard/risk products available on Land Information System Tasmania (LIST)*



To enable the dissemination of the research output from this activity, we have decided to utilise the *Land Information System Tasmania* (LIST) website (URL <http://www.thelist.tas.gov.au>).

The LIST (Land Information System Tasmania) is a whole of government service that delivers integrated land information online. Information available through the LIST can be divided into two areas:

- Online access to title and property information held by the Department of Primary Industries and Water. This service is available to both subscribers and the general public.
- Online delivery of spatial information through LISTmap, including a wide range of administrative, topographic, environmental and socioeconomic data. This includes information on natural resources, roads and community facilities, cadastre (property boundaries), aerial imagery and survey control points.

LIST map is an internet-based map viewer for the LIST. It enables users to view and create maps from over 250 spatial datasets stored in the LIST. Users can create maps and interrogate features within the datasets to find out information about the features.

These services are critical to a number of sectors including conveyancing, real estate, valuation, natural resource management, forestry, mining, agriculture, emergency services and a host of other industries. The LIST has the capability to restrict access to spatial layers such as account details and product access. This functionality is used for Emergency Services related datasets. A screen display of the LIST user interface is shown in [Figure 65](#).

The LIST is managed by the Information and Land Services Division of the Tasmanian Department of Primary Industries and Water (see webpage for contact details).

The LIST contains information on wind hazard and wind risk for both current climate and also projected climate (A2 & B1 IPCC scenarios). Currently, only selected hazard and risk datasets for Tasmania are available via the LIST Web Mapping Interface. All of the datasets are available for supply for use in users own mapping systems. The utility of the information is being assessed through a series of meetings emphasizing interaction and exchange of information with end users and following this process additional datasets will be made available via the LIST Web Mapping Interface. The datasets are:

- (i) wind hazard (speed classified)
- (ii) wind hazard (AS4055 classified)
- (iii) wind risk (loss aggregated to SLA regions).

[Appendix 3](#) contains the data descriptions for each of these datasets.

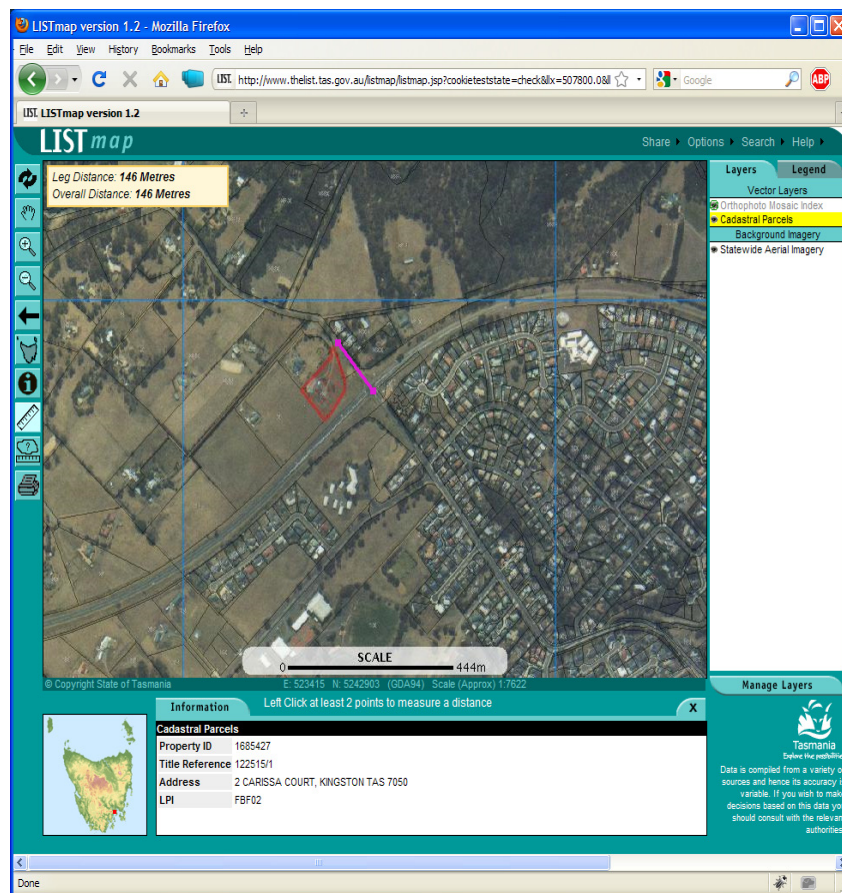


Figure 65. Screen display of the Land Information System Tasmania (LIST) user interface.

In addition to the information available on the LIST, we have developed a standalone tool aimed at desktop/mobile use by the Tasmanian State Emergency Service (SES). The Tasmanian Extreme Wind Hazard Standalone Tool (TEWHST) aims to assist the SES to view the spatial nature of extreme wind hazard (and how it varies depending on the direction of the extreme wind gusts). This information indicates detailed spatial texture for extreme hazard events, which can provide guidance for understanding where the local-scale impact is expected to be the greatest for any particular event depending on the intensity and directional influence of the broad-scale severe storm.

The TEWHST is based on the *NATMAP Digital Maps* developed by Geoscience Australia. The tool provides spatial information at the local scale (25 metre resolution) of the return period extreme wind hazard (3-second gust at 10 metre height; variation with direction) where the broad-scale regional hazard is provided by the Australian and New Zealand Wind Loading Standard (AS/NZS 1170.2, 2011). For more technical information, please see the Users Guide (Yang *et al.* 2011). This user guide should be used in conjunction with the comprehensive user guide provided with the *NATMAP Digital Maps 2008* to access the full functionalities of TEWHST.

## 6. Conclusions

Results demonstrate that dynamical downscaling captures regional climate variability (particularly relevant for extreme wind) and displays significant ability in modelling future changes to the intensity, magnitude and frequency of extreme wind events at the local scale and for considering wind risk associated with residential housing which has utility in adaptation and emergency planning applications.

The Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC), Hobart, has produced high-resolution climate change projections for the Australian state of Tasmania as part of the *Climate Futures for Tasmania* project. A key component of the project established possible changes to climatic extreme events as a consequence of climate change up to the end of the 21<sup>st</sup> century. Natural climate variability produces extreme climatic events in Tasmania including severe storms. These events can have devastating and wide-ranging costs to all sectors of society, including agriculture, water resources and emergency management. The impact on residential housing is considered here. The change to frequency and magnitude of extreme wind events across Tasmania due to anthropogenic interference of the climate through the enhancement of the greenhouse gases has been assessed, and resulting impact on wind risk has been derived.

### **Hazard**

We have presented a review of wind hazard over the Tasmanian region utilising computational models of wind hazard to develop a spatial understanding of the return period wind speeds due to synoptic storms and thunderstorms. We have introduced a preliminary understanding of the current-climate wind hazard for the Tasmanian region by using a computational methodology for each of the component hazard types (thunderstorms and synoptic winds). Where possible we have compared our analysis with observations. Resulting maps of current climate modelled wind hazard display in general a lower magnitude compared to the AS/NZS 1170.2 design wind speeds. Notable areas of exception are the northeast corner and the Bass Strait islands.

The modeling methodology allowed us to also consider how the wind hazard would be affected by climate change by employing the output of 21<sup>st</sup> century climate simulations. The hazard was determined by averaging the output of six climate models each being forced by two climate change greenhouse gas scenarios. Resulting maps of future climate modelled wind hazard in general show small increases from current climate for Tasmania. The hazard for Hobart is maintained at present levels and this result does not vary to a great extent within the range of the climate scenarios.

### **Risk**

The wind risk methodology detailed in this report has provided the first ever assessment of wind risk to residential housing in the Tasmanian region (the first region within Australia to be considered). The annualised loss assessment was produced utilising the wind loading standard as a preliminary substitute for wind hazard. The level of risk was influenced by the level of hazard as well as by the number of older structures within the building population. When population projections were utilised to infer increased number of buildings (all built to the present standard), the proportion of legacy buildings within the building population declined resulting in a decline in wind risk. The improved understanding of the wind vulnerability for residential structures (provided by this study through heuristic vulnerability curve development) has been successfully implemented. The results should only be considered as a preliminary assessment of the severe wind risk to residential housing in the Tasmanian region as validation of the risk estimates against insurance industry data is still to be undertaken (planned activity).

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## Appendix 1.

# Graphical representation of the outputs for each stage of the risk assessment process

This Appendix utilises the Hobart area of the Tasmanian region to provide a graphical representation of the outputs for each stage of the risk assessment. These information layers include:

Map of the Hobart region

Terrain classification

Terrain wind multiplier

Shielding wind multiplier

Topographic wind multiplier

Combined (m4) wind multipliers (terrain, topography, shielding and direction)

500-year return period wind hazard

500-year return period impact/loss

Annualised Loss



Figure A1. Map of the Hobart region.

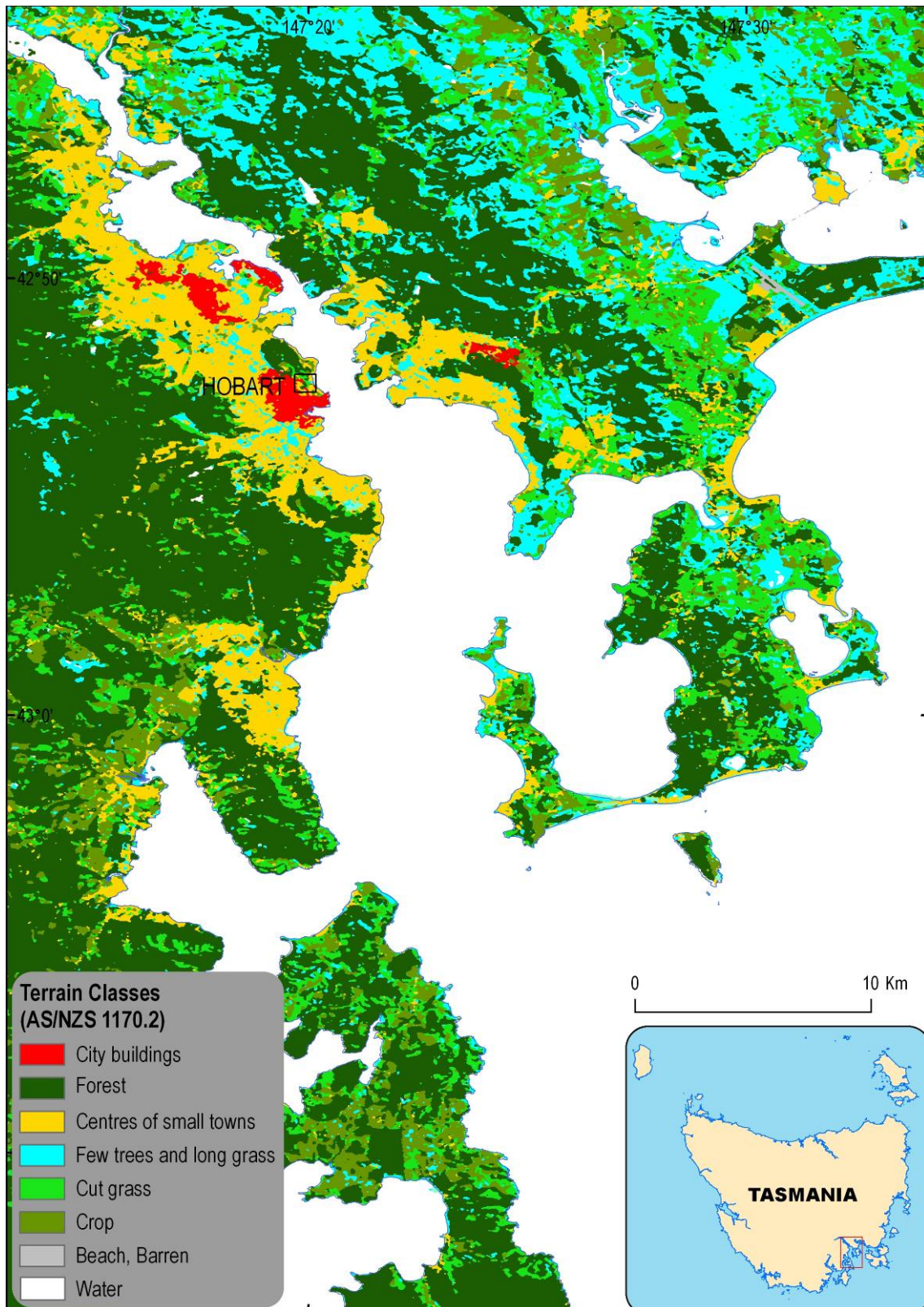


Figure A2. Terrain classification map (Hobart region)



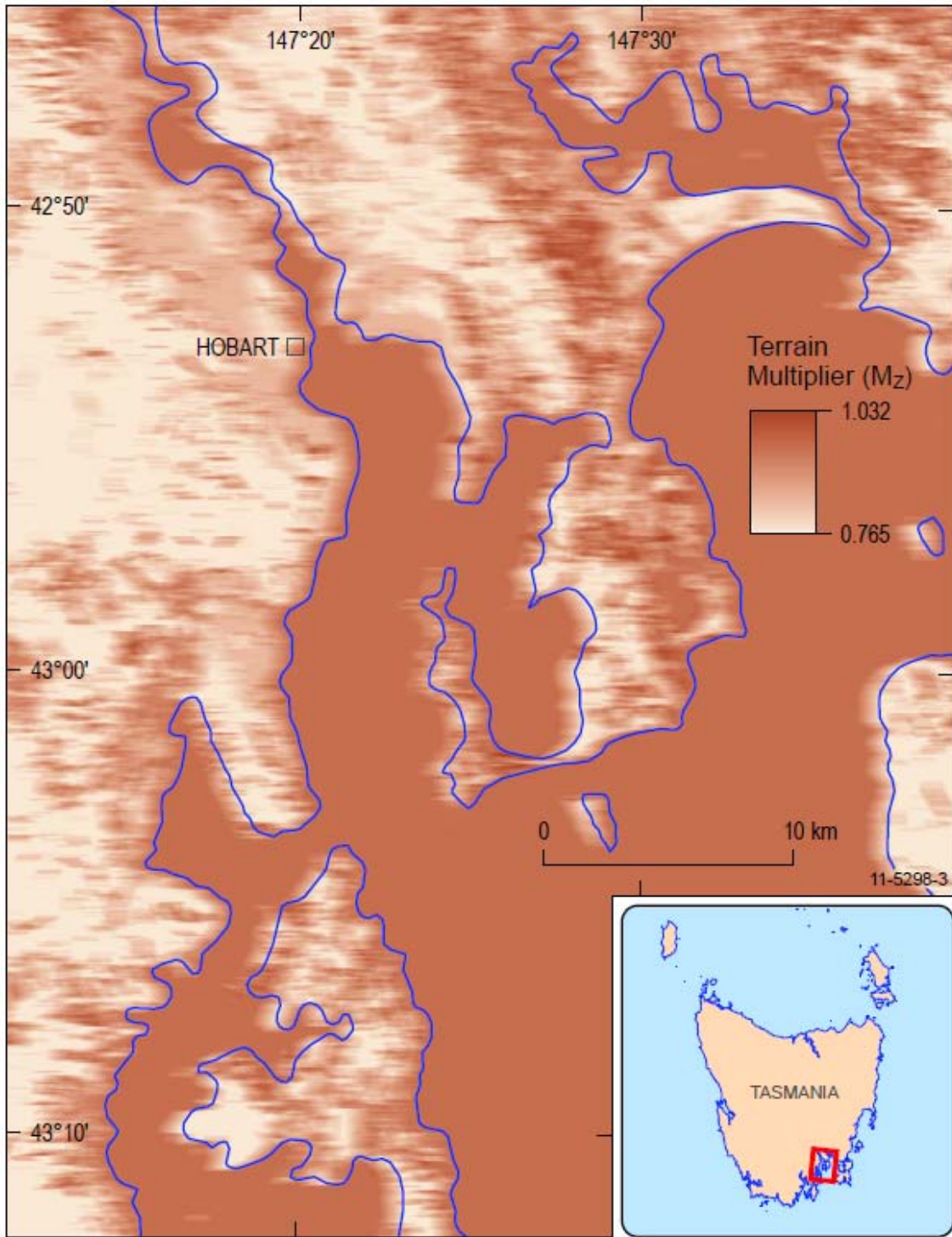


Figure A3. Terrain Multiplier (Hobart region)

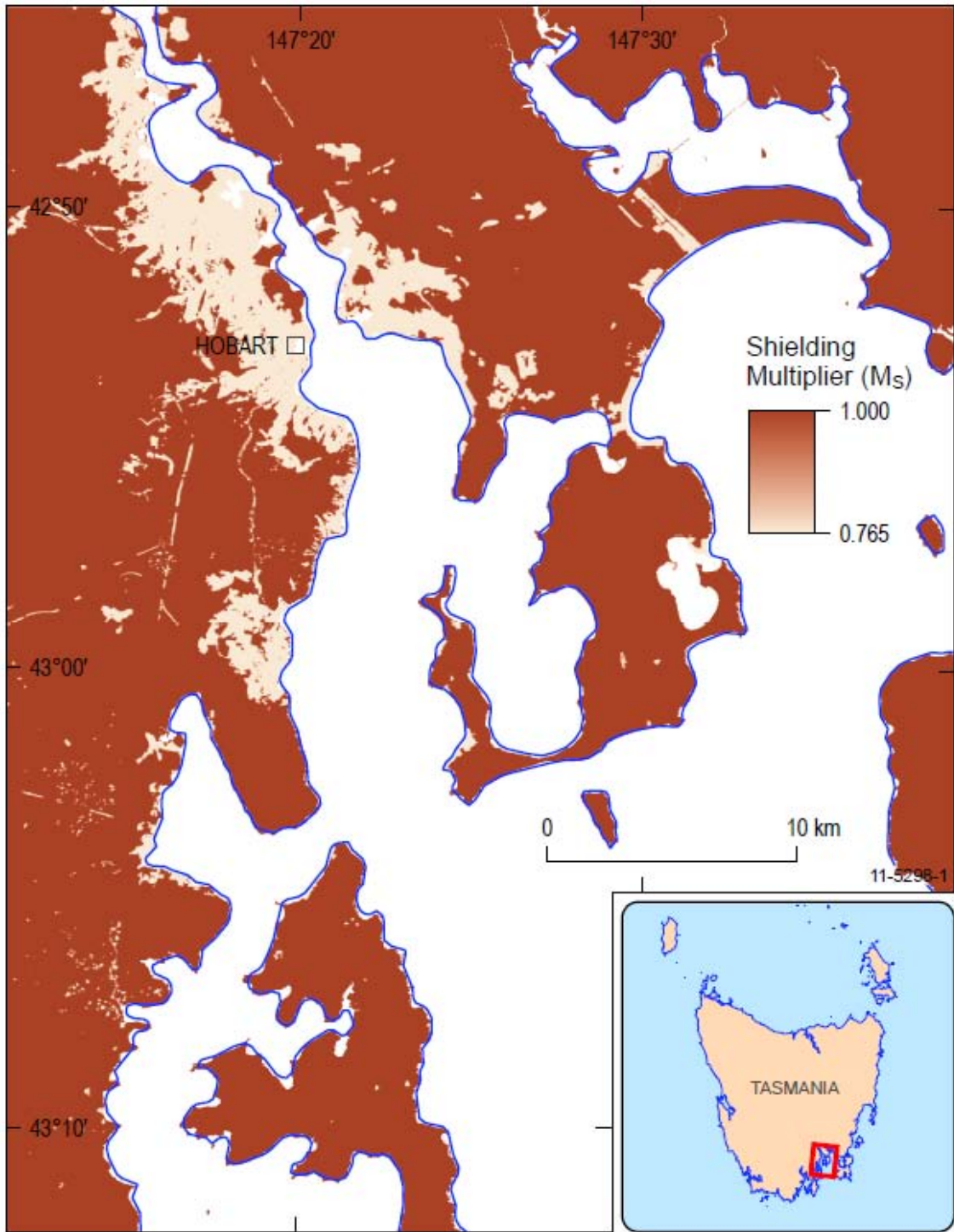


Figure A4. Shielding wind multiplier (Hobart region)

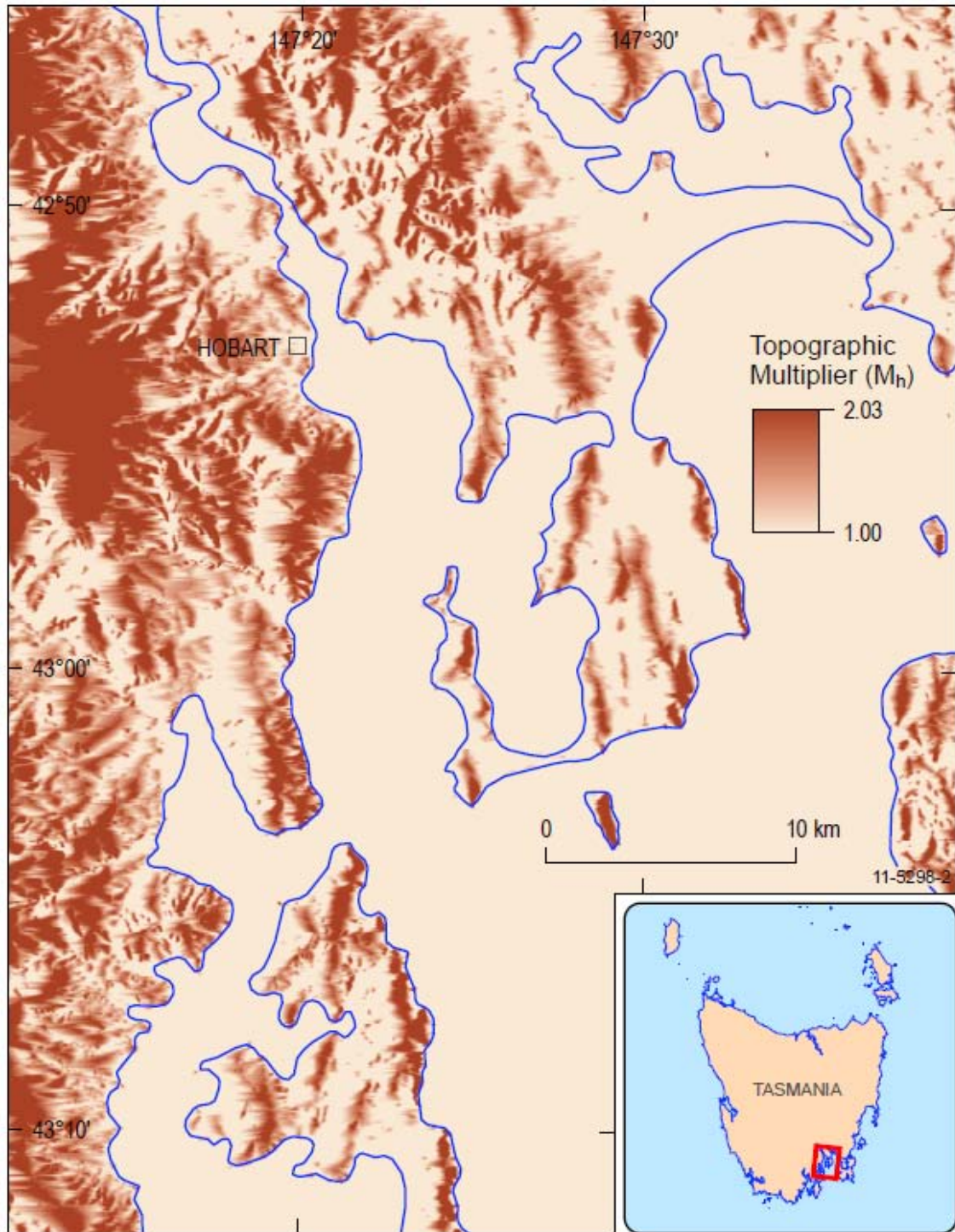


Figure A5. Topographic wind multiplier (Hobart region)

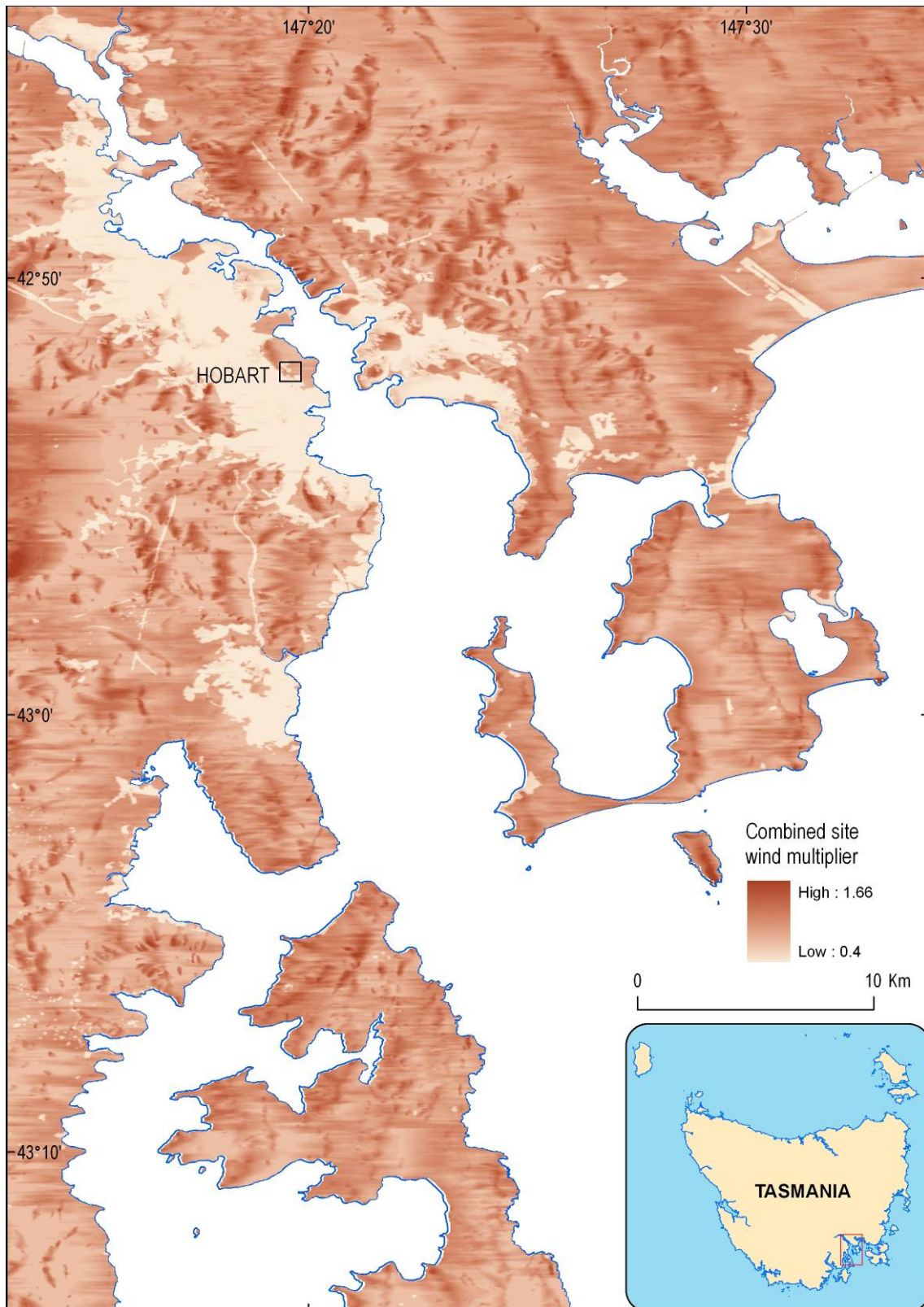


Figure A6. Combined (M4) wind multipliers (Hobart region) – westerly direction

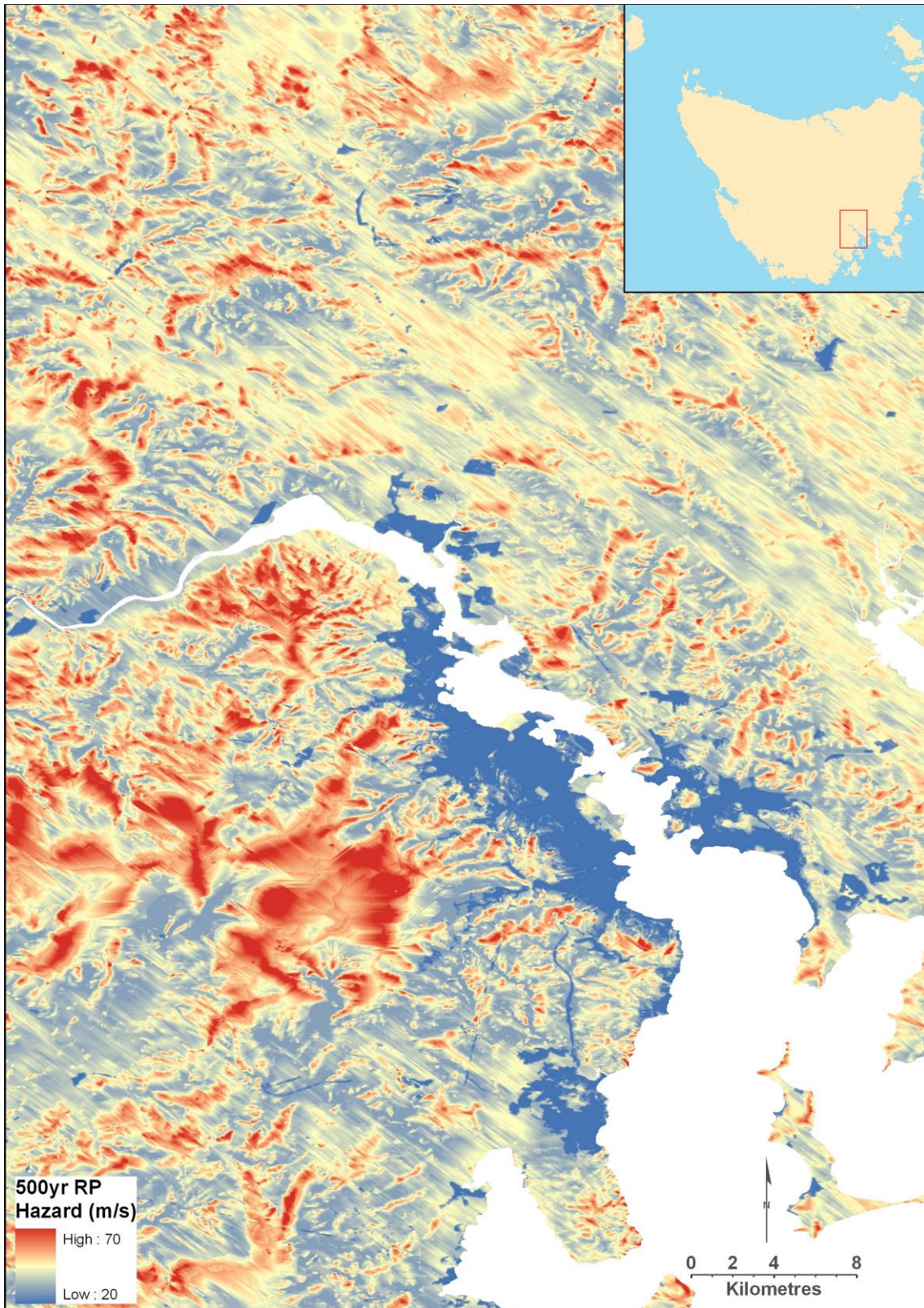


Figure A7. 500 year return period local design-wind map (Hobart region) consisting of the AS/NZS 1170.2 500 year RP regional design wind speed (45 m/s) multiplied by the local M4 multiplier.

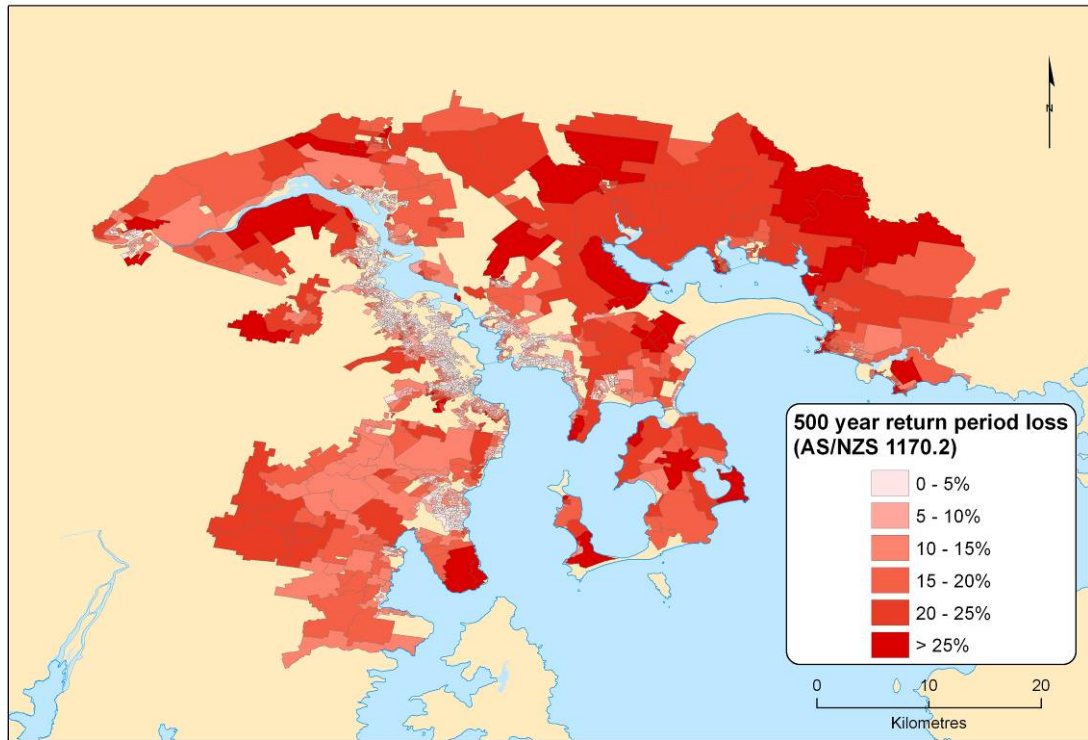


Figure A8. 500-year return period loss. The hazard depicted in Figure A6 has been used in this assessment, and the buildings-scale risk has been aggregated to Australian Bureau of Statistics (ABS) meshblock areas.

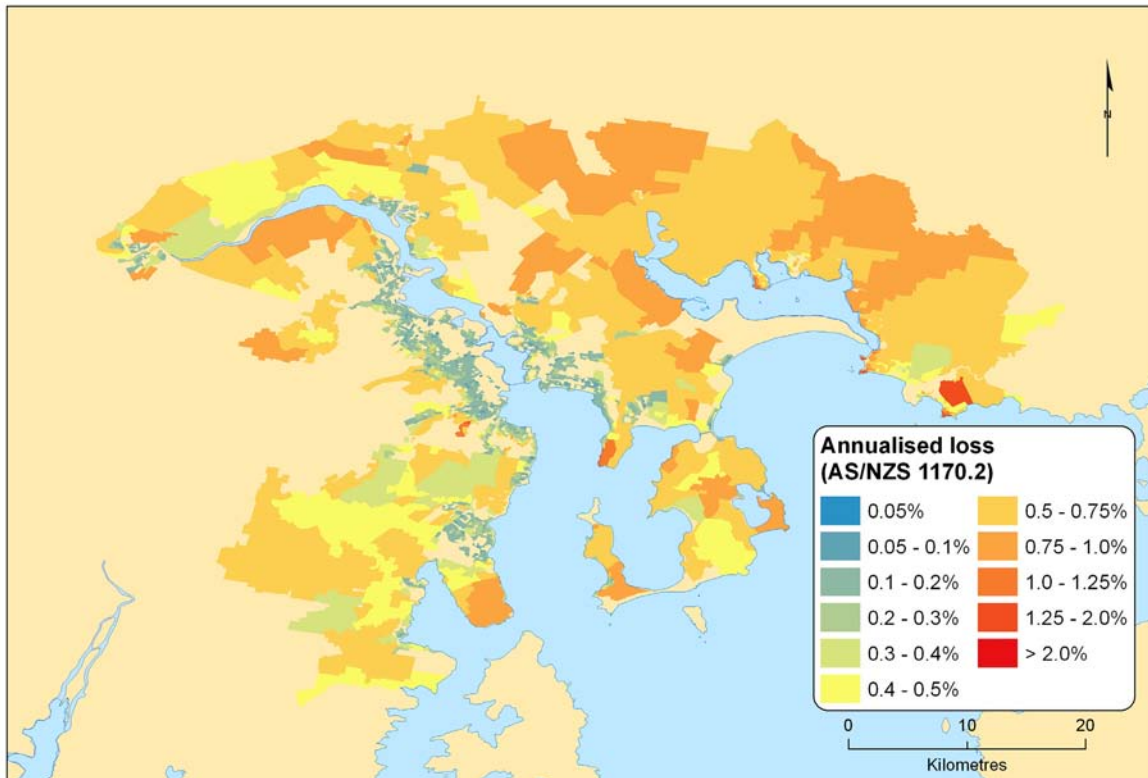


Figure A9. Annualised loss. The loss for 10-year to 2000-year return period hazard events has been aggregated at the building-scale, and then further aggregated to Australian Bureau of Statistics (ABS) meshblock areas.

## Appendix 2.

### Wind Risk (% of the replacement value of the residential building stock)

This Appendix shows the wind risk, expressed as the % of the replacement value of the residential building stock, for each of the Tasmanian SLA (Statistical Local Area) regions and for a range of future time intervals (2020 – 2090), three population projections and two climate change greenhouse gas scenarios (A2 & B1).



Table 1. Annualised Loss - Current climate

SLA_CODE	SLA_NAME	2009 value \$A million	for hazard AS/NZS 1170.2	for C20C modelled hazard
605050410	Brighton (M)	\$1,537	0.41	0.31
605051410	Clarence (C)	\$5,100	0.33	0.26
605051511	Derwent Valley (M) - Pt A	\$697	0.35	0.25
605052610	Glenorchy (C)	\$4,315	0.20	0.17
605052811	Hobart (C) - Inner	\$100	0.09	0.07
605052812	Hobart (C) - Remainder	\$5,170	0.21	0.19
605053611	Kingborough (M) - Pt A	\$3,159	0.30	0.49
605054811	Sorell (M) - Pt A	\$1,581	0.65	0.43
610051010	Central Highlands (M)	\$876	0.82	0.89
610051512	Derwent Valley (M) - Pt B	\$423	0.79	0.54
610052410	Glamorgan/Spring Bay (M)	\$1,067	0.37	0.48
610053010	Huon Valley (M)	\$1,994	0.55	0.49
610053612	Kingborough (M) - Pt B	\$566	0.57	0.93
610054812	Sorell (M) - Pt B	\$168	0.71	0.72
610055010	Southern Midlands (M)	\$794	0.67	0.60
610055210	Tasman (M)	\$556	0.54	0.84
615052211	George Town (M) - Pt A	\$644	0.52	1.15
615054011	Launceston (C) - Inner	\$15	0.14	0.10
615054012	Launceston (C) - Pt B	\$6,048	0.29	0.20
615054211	Meander Valley (M) - Pt A	\$895	0.35	0.25
615054611	Northern Midlands (M) - Pt A	\$954	0.51	0.31
615055811	West Tamar (M) - Pt A	\$2,419	0.61	0.60
615102212	George Town (M) - Pt B	\$276	0.59	0.95
615104013	Launceston (C) - Pt C	\$485	1.03	0.96
615104212	Meander Valley (M) - Pt B	\$1,390	0.97	0.48
615104612	Northern Midlands (M) - Pt B	\$728	0.78	0.70
615105812	West Tamar (M) - Pt B	\$272	1.10	0.89
615150210	Break O'Day (M)	\$1,303	0.45	0.71
615151810	Dorset (M)	\$1,065	0.60	0.76
615152010	Flinders (M)	\$148	0.84	3.67
620050611	Burnie (C) - Pt A	\$1,634	0.43	0.21
620050811	Central Coast (M) - Pt A	\$1,877	0.52	0.32
620051610	Devonport (C)	\$2,612	0.35	0.24
620053811	Latrobe (M) - Pt A	\$1,147	0.61	0.48
620055411	Waratah/Wynyard (M) - Pt A	\$1,294	0.63	0.27
620100612	Burnie (C) - Pt B	\$270	1.33	0.61
620100812	Central Coast (M) - Pt B	\$451	1.65	0.83
620101210	Circular Head (M)	\$1,088	0.93	0.58
620103210	Kentish (M)	\$906	1.17	0.47
620103410	King Island (M)	\$260	0.85	3.46
620103812	Latrobe (M) - Pt B	\$104	1.41	0.74
620105412	Waratah/Wynyard (M) - Pt B	\$409	1.43	0.65
620155610	West Coast (M)	\$617	0.23	0.15

**Table 2.** Annualised Loss – Series A population projection; A2 climate change projection

SLA_CODE	2020	2030	2040	2050	2060	2070	2080	2090
605050410	0.27	0.33	0.35	0.38	0.41	0.48	0.54	0.49
605051410	0.24	0.25	0.26	0.28	0.36	0.37	0.40	0.43
605051511	0.26	0.34	0.36	0.41	0.46	0.44	0.46	0.46
605052610	0.20	0.25	0.25	0.30	0.40	0.26	0.28	0.28
605052811	0.08	0.08	0.09	0.09	0.13	0.14	0.15	0.13
605052812	0.22	0.26	0.28	0.29	0.41	0.45	0.47	0.40
605053611	0.49	0.54	0.56	0.49	0.52	0.55	0.57	0.50
605054811	0.39	0.38	0.39	0.43	0.41	0.44	0.41	0.45
610051010	0.88	0.88	0.91	0.85	0.77	0.81	0.89	0.68
610051512	0.54	0.58	0.57	0.67	0.69	0.65	0.52	0.52
610052410	0.53	0.54	0.54	0.52	0.49	0.52	0.60	0.50
610053010	0.54	0.54	0.54	0.58	0.50	0.52	0.54	0.47
610053612	0.96	0.89	0.86	0.87	0.83	0.83	0.79	0.86
610054812	0.70	0.70	0.72	0.75	0.83	0.83	0.91	0.85
610055010	0.55	0.60	0.59	0.68	0.75	0.70	0.67	0.64
610055210	0.88	0.79	0.74	0.78	0.83	0.94	0.97	0.94
615052211	1.13	1.07	1.01	1.06	1.14	1.14	1.21	0.97
615054011	0.09	0.09	0.10	0.11	0.11	0.09	0.11	0.31
615054012	0.21	0.22	0.23	0.27	0.28	0.26	0.33	0.45
615054211	0.24	0.25	0.24	0.26	0.30	0.27	0.31	0.53
615054611	0.32	0.33	0.35	0.43	0.35	0.44	0.33	0.57
615055811	0.61	0.62	0.62	0.58	0.59	0.56	0.64	0.86
615102212	0.85	0.83	0.81	0.88	0.86	0.87	1.03	0.83
615104013	0.90	0.82	0.86	0.91	0.87	0.88	0.99	0.80
615104212	0.50	0.48	0.46	0.55	0.54	0.56	0.51	0.56
615104612	0.70	0.67	0.69	0.66	0.64	0.67	0.78	0.66
615105812	0.83	0.80	0.77	0.92	0.94	0.95	0.97	1.58
615150210	0.77	0.74	0.73	0.72	0.75	0.85	0.96	0.70
615151810	0.76	0.69	0.71	0.79	0.83	0.96	1.11	0.84
615152010	3.60	3.24	3.30	3.43	3.22	3.25	2.74	2.73
620050611	0.24	0.24	0.26	0.29	0.28	0.30	0.41	0.36
620050811	0.36	0.34	0.38	0.41	0.40	0.34	0.45	0.39
620051610	0.25	0.26	0.26	0.30	0.30	0.39	0.35	0.27
620053811	0.45	0.44	0.47	0.50	0.41	0.44	0.56	0.50
620055411	0.30	0.30	0.32	0.34	0.38	0.37	0.47	0.41
620100612	0.64	0.61	0.65	0.62	0.62	0.62	0.70	0.60
620100812	0.89	0.78	0.79	0.83	0.80	0.83	1.02	0.91
620101210	0.58	0.57	0.57	0.65	0.69	0.79	0.80	0.69
620103210	0.48	0.47	0.46	0.50	0.48	0.50	0.59	0.53
620103410	3.41	3.13	2.89	3.34	3.37	2.48	2.37	2.68
620103812	0.72	0.69	0.64	0.66	0.67	0.67	0.74	0.72
620105412	0.66	0.64	0.63	0.67	0.64	0.63	0.75	0.65
620155610	0.17	0.20	0.23	0.30	0.32	0.20	0.23	0.26

**Table 3.** Annualised Loss – Series A population projection; B1 climate change projection

SLA_CODE	2020	2030	2040	2050	2060	2070	2080	2090
605050410	0.31	0.33	0.32	0.39	0.35	0.40	0.37	0.33
605051410	0.26	0.26	0.26	0.28	0.32	0.31	0.28	0.26
605051511	0.29	0.31	0.33	0.39	0.35	0.38	0.38	0.38
605052610	0.19	0.23	0.26	0.32	0.34	0.33	0.38	0.34
605052811	0.07	0.07	0.08	0.10	0.12	0.10	0.10	0.08
605052812	0.20	0.23	0.25	0.31	0.37	0.31	0.33	0.31
605053611	0.51	0.53	0.52	0.43	0.47	0.61	0.45	0.42
605054811	0.42	0.40	0.39	0.41	0.36	0.41	0.33	0.33
610051010	0.88	0.90	0.87	0.81	0.76	0.81	0.83	0.78
610051512	0.57	0.57	0.57	0.63	0.58	0.56	0.57	0.56
610052410	0.55	0.54	0.54	0.57	0.58	0.50	0.59	0.61
610053010	0.51	0.53	0.54	0.59	0.46	0.56	0.59	0.40
610053612	0.93	0.89	0.85	0.91	0.88	0.66	0.83	0.82
610054812	0.69	0.78	0.71	0.76	0.75	0.67	0.68	0.61
610055010	0.59	0.61	0.59	0.59	0.58	0.63	0.58	0.55
610055210	0.78	0.80	0.74	0.87	0.80	0.69	0.68	0.69
615052211	1.17	1.07	0.96	1.00	1.04	0.77	0.92	0.79
615054011	0.10	0.10	0.09	0.10	0.10	0.10	0.10	0.10
615054012	0.23	0.23	0.24	0.26	0.26	0.27	0.26	0.27
615054211	0.28	0.25	0.25	0.29	0.33	0.30	0.25	0.27
615054611	0.37	0.34	0.40	0.43	0.32	0.45	0.39	0.40
615055811	0.64	0.59	0.59	0.54	0.55	0.58	0.48	0.62
615102212	0.89	0.82	0.77	0.77	0.80	0.68	0.73	0.62
615104013	0.94	0.93	0.92	0.83	0.82	0.85	0.74	0.81
615104212	0.56	0.46	0.47	0.50	0.51	0.51	0.49	0.47
615104612	0.71	0.69	0.67	0.63	0.63	0.69	0.56	0.69
615105812	0.89	0.81	0.78	0.85	0.85	0.72	0.79	0.71
615150210	0.76	0.71	0.75	0.63	0.65	0.67	0.63	0.63
615151810	0.75	0.71	0.63	0.69	0.74	0.58	0.70	0.63
615152010	3.50	3.11	3.09	3.05	2.86	2.28	2.89	2.64
620050611	0.25	0.24	0.22	0.25	0.30	0.26	0.28	0.25
620050811	0.36	0.34	0.32	0.36	0.38	0.36	0.42	0.38
620051610	0.25	0.25	0.27	0.26	0.29	0.25	0.32	0.29
620053811	0.48	0.44	0.46	0.48	0.40	0.43	0.38	0.50
620055411	0.32	0.29	0.28	0.32	0.32	0.32	0.32	0.30
620100612	0.67	0.58	0.57	0.58	0.59	0.53	0.57	0.49
620100812	0.92	0.76	0.71	0.73	0.72	0.66	0.71	0.65
620101210	0.68	0.59	0.54	0.62	0.63	0.56	0.51	0.49
620103210	0.61	0.46	0.46	0.47	0.44	0.44	0.43	0.43
620103410	3.23	2.98	2.90	3.00	2.90	2.26	2.50	2.36
620103812	0.85	0.64	0.63	0.62	0.62	0.59	0.61	0.56
620105412	0.72	0.64	0.62	0.62	0.62	0.58	0.57	0.51
620155610	0.20	0.22	0.26	0.26	0.27	0.26	0.27	0.27

**Table 4.** Annualised Loss – Series B population projection; A2 climate change projection

SLA_CODE	2020	2030	2040	2050	2060	2070	2080	2090
605050410	0.28	0.33	0.36	0.38	0.42	0.49	0.55	0.49
605051410	0.24	0.25	0.26	0.28	0.36	0.37	0.40	0.42
605051511	0.26	0.32	0.34	0.39	0.43	0.41	0.43	0.43
605052610	0.19	0.23	0.22	0.25	0.36	0.27	0.29	0.30
605052811	0.08	0.08	0.09	0.09	0.13	0.14	0.15	0.13
605052812	0.22	0.25	0.26	0.27	0.38	0.42	0.45	0.38
605053611	0.48	0.53	0.54	0.54	0.57	0.61	0.63	0.55
605054811	0.40	0.40	0.39	0.46	0.44	0.47	0.44	0.48
610051010	0.90	0.91	0.97	1.04	0.95	0.98	1.08	0.81
610051512	0.54	0.59	0.59	0.71	0.74	0.67	0.61	0.61
610052410	0.53	0.53	0.54	0.63	0.58	0.62	0.71	0.59
610053010	0.53	0.53	0.53	0.56	0.58	0.61	0.61	0.54
610053612	0.98	0.95	0.95	1.14	1.06	1.07	1.00	0.96
610054812	0.72	0.75	0.82	0.89	0.98	0.98	1.08	0.99
610055010	0.56	0.62	0.61	0.73	0.81	0.75	0.81	0.68
610055210	0.93	0.89	0.89	1.00	1.06	1.17	1.18	1.16
615052211	1.19	1.18	1.19	1.34	1.41	1.40	1.47	1.18
615054011	0.09	0.10	0.10	0.11	0.11	0.09	0.12	0.32
615054012	0.20	0.20	0.21	0.24	0.25	0.23	0.29	0.50
615054211	0.23	0.25	0.24	0.26	0.30	0.26	0.31	0.61
615054611	0.31	0.31	0.32	0.38	0.39	0.39	0.37	0.61
615055811	0.61	0.62	0.64	0.70	0.71	0.67	0.75	1.01
615102212	0.87	0.87	0.94	1.10	1.06	1.07	1.25	1.01
615104013	0.91	0.85	0.92	1.12	1.06	1.06	1.19	0.97
615104212	0.50	0.49	0.48	0.58	0.58	0.60	0.62	0.69
615104612	0.71	0.72	0.70	0.79	0.77	0.80	0.91	0.78
615105812	0.86	0.85	0.85	1.06	1.07	1.09	1.20	1.96
615150210	0.78	0.75	0.75	0.88	0.91	1.02	1.13	0.83
615151810	0.79	0.74	0.79	0.94	0.97	1.11	1.26	0.97
615152010	3.80	3.66	4.00	4.49	4.18	4.17	3.54	3.49
620050611	0.23	0.23	0.24	0.27	0.26	0.28	0.38	0.34
620050811	0.35	0.33	0.36	0.38	0.37	0.39	0.50	0.44
620051610	0.24	0.25	0.24	0.26	0.27	0.34	0.38	0.30
620053811	0.46	0.47	0.45	0.48	0.48	0.50	0.63	0.56
620055411	0.30	0.29	0.31	0.34	0.37	0.36	0.45	0.40
620100612	0.66	0.64	0.72	0.77	0.70	0.70	0.85	0.73
620100812	0.92	0.84	0.90	0.99	0.95	0.99	1.21	1.08
620101210	0.60	0.61	0.64	0.76	0.81	0.93	0.92	0.79
620103210	0.49	0.49	0.49	0.55	0.52	0.54	0.65	0.57
620103410	3.58	3.50	3.48	4.30	4.25	3.19	3.05	3.39
620103812	0.75	0.75	0.72	0.77	0.79	0.79	0.87	0.85
620105412	0.67	0.68	0.72	0.81	0.78	0.77	0.91	0.78
620155610	0.16	0.16	0.18	0.21	0.23	0.20	0.22	0.26

**Table 5.** Annualised Loss – Series B population projection; B1 climate change projection

SLA_CODE	2020	2030	2040	2050	2060	2070	2080	2090
605050410	0.31	0.34	0.32	0.39	0.36	0.41	0.37	0.34
605051410	0.26	0.26	0.26	0.28	0.32	0.30	0.28	0.26
605051511	0.29	0.30	0.31	0.36	0.33	0.36	0.36	0.36
605052610	0.18	0.22	0.23	0.27	0.30	0.30	0.34	0.30
605052811	0.07	0.07	0.08	0.10	0.11	0.10	0.10	0.08
605052812	0.20	0.22	0.23	0.29	0.34	0.30	0.31	0.29
605053611	0.50	0.52	0.51	0.48	0.52	0.60	0.49	0.46
605054811	0.43	0.41	0.41	0.45	0.39	0.44	0.36	0.35
610051010	0.90	0.94	0.93	1.00	0.93	0.88	0.90	0.84
610051512	0.58	0.58	0.59	0.67	0.59	0.57	0.59	0.59
610052410	0.55	0.54	0.53	0.57	0.58	0.50	0.58	0.62
610053010	0.51	0.52	0.53	0.57	0.54	0.54	0.58	0.46
610053612	0.96	0.94	0.94	1.04	1.01	0.75	0.94	0.91
610054812	0.72	0.85	0.81	0.92	0.89	0.79	0.80	0.71
610055010	0.60	0.62	0.63	0.64	0.62	0.68	0.62	0.58
610055210	0.82	0.89	0.89	1.12	1.01	0.74	0.85	0.85
615052211	1.22	1.13	1.04	1.26	1.31	0.84	1.14	0.97
615054011	0.10	0.10	0.10	0.11	0.10	0.11	0.10	0.10
615054012	0.22	0.21	0.22	0.23	0.23	0.24	0.24	0.24
615054211	0.28	0.25	0.24	0.29	0.33	0.30	0.25	0.27
615054611	0.36	0.32	0.36	0.37	0.36	0.40	0.36	0.36
615055811	0.64	0.60	0.60	0.66	0.66	0.59	0.58	0.63
615102212	0.93	0.86	0.90	0.97	0.99	0.74	0.90	0.76
615104013	0.96	1.01	0.99	1.03	1.00	0.94	0.90	0.88
615104212	0.57	0.47	0.49	0.53	0.54	0.55	0.52	0.50
615104612	0.73	0.75	0.76	0.76	0.76	0.72	0.66	0.70
615105812	0.92	0.86	0.86	0.98	0.98	0.83	0.89	0.81
615150210	0.79	0.77	0.77	0.77	0.78	0.70	0.76	0.75
615151810	0.77	0.76	0.71	0.81	0.86	0.68	0.81	0.73
615152010	3.69	3.52	3.77	4.03	3.76	3.01	3.74	3.41
620050611	0.25	0.24	0.21	0.24	0.28	0.25	0.26	0.23
620050811	0.36	0.33	0.30	0.33	0.36	0.34	0.40	0.36
620051610	0.25	0.24	0.24	0.23	0.26	0.22	0.29	0.27
620053811	0.50	0.43	0.44	0.46	0.46	0.41	0.44	0.48
620055411	0.31	0.29	0.28	0.32	0.31	0.31	0.32	0.30
620100612	0.69	0.62	0.62	0.67	0.68	0.61	0.65	0.55
620100812	0.95	0.81	0.80	0.87	0.85	0.78	0.84	0.77
620101210	0.70	0.64	0.61	0.73	0.75	0.66	0.59	0.57
620103210	0.62	0.48	0.50	0.52	0.48	0.49	0.47	0.47
620103410	3.40	3.34	3.49	3.90	3.74	2.96	3.20	3.04
620103812	0.88	0.69	0.71	0.74	0.73	0.70	0.72	0.65
620105412	0.73	0.68	0.68	0.71	0.71	0.66	0.64	0.57
620155610	0.19	0.18	0.20	0.17	0.19	0.19	0.20	0.21

**Table 6.** Annualised Loss – Series C population projection; A2 climate change projection

SLA_CODE	2020	2030	2040	2050	2060	2070	2080	2090
605050410	0.28	0.33	0.36	0.39	0.42	0.50	0.56	0.50
605051410	0.24	0.25	0.26	0.28	0.36	0.37	0.40	0.42
605051511	0.25	0.31	0.32	0.36	0.40	0.38	0.40	0.41
605052610	0.18	0.21	0.20	0.21	0.31	0.28	0.30	0.31
605052811	0.08	0.08	0.09	0.09	0.13	0.14	0.15	0.13
605052812	0.21	0.24	0.25	0.24	0.35	0.39	0.42	0.36
605053611	0.47	0.51	0.53	0.60	0.62	0.67	0.69	0.61
605054811	0.41	0.42	0.39	0.49	0.47	0.51	0.47	0.51
610051010	0.91	0.93	0.99	1.06	1.01	1.10	1.25	0.97
610051512	0.54	0.60	0.60	0.71	0.75	0.68	0.69	0.71
610052410	0.53	0.53	0.53	0.64	0.61	0.68	0.82	0.70
610053010	0.53	0.52	0.52	0.55	0.61	0.66	0.68	0.61
610053612	1.00	0.98	0.98	1.16	1.16	1.23	1.22	1.10
610054812	0.74	0.79	0.85	0.91	1.05	1.08	1.24	1.17
610055010	0.56	0.62	0.62	0.73	0.83	0.78	0.94	0.72
610055210	0.97	0.94	0.93	1.02	1.15	1.35	1.41	1.45
615052211	1.23	1.24	1.24	1.36	1.52	1.58	1.72	1.44
615054011	0.09	0.10	0.10	0.11	0.11	0.09	0.12	0.33
615054012	0.20	0.20	0.21	0.23	0.23	0.21	0.26	0.57
615054211	0.22	0.25	0.24	0.26	0.29	0.26	0.30	0.70
615054611	0.31	0.30	0.32	0.37	0.41	0.37	0.41	0.66
615055811	0.61	0.63	0.64	0.71	0.76	0.74	0.86	1.20
615102212	0.88	0.89	0.98	1.11	1.13	1.20	1.46	1.22
615104013	0.93	0.87	0.93	1.14	1.13	1.18	1.37	1.16
615104212	0.51	0.50	0.48	0.59	0.59	0.62	0.72	0.84
615104612	0.71	0.75	0.70	0.80	0.82	0.88	1.04	0.93
615105812	0.87	0.88	0.87	1.08	1.12	1.17	1.41	2.38
615150210	0.79	0.76	0.75	0.89	0.97	1.13	1.29	0.99
615151810	0.81	0.77	0.82	0.95	1.03	1.21	1.40	1.12
615152010	3.96	3.87	4.19	4.58	4.56	4.81	4.31	4.42
620050611	0.23	0.23	0.24	0.26	0.25	0.27	0.36	0.31
620050811	0.34	0.32	0.35	0.38	0.36	0.42	0.56	0.50
620051610	0.24	0.24	0.23	0.26	0.26	0.32	0.41	0.33
620053811	0.47	0.49	0.45	0.48	0.50	0.55	0.70	0.64
620055411	0.30	0.29	0.31	0.33	0.36	0.36	0.44	0.39
620100612	0.67	0.66	0.74	0.78	0.73	0.76	0.99	0.88
620100812	0.95	0.88	0.92	1.01	1.00	1.09	1.37	1.26
620101210	0.61	0.63	0.66	0.77	0.85	1.02	1.04	0.91
620103210	0.49	0.50	0.50	0.56	0.54	0.57	0.70	0.63
620103410	3.72	3.69	3.64	4.38	4.60	3.67	3.69	4.23
620103812	0.76	0.77	0.75	0.78	0.83	0.87	0.99	1.00
620105412	0.69	0.70	0.75	0.83	0.83	0.86	1.06	0.93
620155610	0.14	0.14	0.16	0.20	0.19	0.19	0.20	0.26

**Table 7.** Annualised Loss – Series C population projection; B1 climate change projection

SLA_CODE	2020	2030	2040	2050	2060	2070	2080	2090
605050410	0.31	0.34	0.33	0.40	0.36	0.42	0.38	0.34
605051410	0.26	0.26	0.26	0.28	0.32	0.30	0.28	0.26
605051511	0.28	0.28	0.29	0.33	0.31	0.33	0.34	0.34
605052610	0.17	0.20	0.20	0.23	0.26	0.26	0.30	0.27
605052811	0.07	0.07	0.08	0.10	0.11	0.10	0.10	0.08
605052812	0.19	0.21	0.22	0.26	0.32	0.28	0.29	0.27
605053611	0.49	0.51	0.49	0.53	0.58	0.59	0.53	0.50
605054811	0.43	0.42	0.43	0.48	0.42	0.47	0.38	0.38
610051010	0.91	0.95	0.94	1.02	1.00	0.93	0.97	0.90
610051512	0.58	0.58	0.59	0.67	0.60	0.58	0.61	0.61
610052410	0.55	0.54	0.53	0.57	0.57	0.49	0.58	0.62
610053010	0.51	0.51	0.52	0.57	0.57	0.53	0.56	0.53
610053612	0.99	0.97	0.96	1.05	1.06	0.82	1.05	1.03
610054812	0.74	0.88	0.83	0.93	0.95	0.88	0.92	0.84
610055010	0.61	0.63	0.63	0.64	0.63	0.71	0.65	0.61
610055210	0.85	0.94	0.93	1.14	1.11	0.78	1.03	1.07
615052211	1.26	1.16	1.06	1.28	1.41	0.90	1.35	1.18
615054011	0.10	0.10	0.10	0.11	0.11	0.11	0.10	0.10
615054012	0.22	0.21	0.21	0.22	0.22	0.23	0.21	0.22
615054211	0.28	0.25	0.24	0.29	0.32	0.29	0.25	0.27
615054611	0.35	0.31	0.35	0.37	0.37	0.37	0.32	0.32
615055811	0.64	0.60	0.60	0.67	0.71	0.61	0.67	0.65
615102212	0.96	0.88	0.94	0.98	1.07	0.78	1.05	0.93
615104013	0.98	1.06	1.01	1.04	1.07	1.00	1.04	0.97
615104212	0.58	0.48	0.50	0.54	0.55	0.57	0.54	0.53
615104612	0.75	0.78	0.79	0.77	0.81	0.73	0.76	0.71
615105812	0.94	0.88	0.88	0.99	1.02	0.90	0.99	0.91
615150210	0.81	0.80	0.78	0.78	0.84	0.71	0.87	0.90
615151810	0.79	0.79	0.73	0.82	0.91	0.75	0.92	0.85
615152010	3.84	3.73	3.95	4.11	4.12	3.52	4.55	4.33
620050611	0.25	0.23	0.21	0.24	0.27	0.24	0.25	0.22
620050811	0.35	0.32	0.30	0.33	0.35	0.32	0.37	0.33
620051610	0.24	0.23	0.23	0.22	0.25	0.20	0.26	0.24
620053811	0.51	0.42	0.44	0.46	0.49	0.40	0.49	0.46
620055411	0.31	0.29	0.28	0.31	0.31	0.31	0.31	0.29
620100612	0.70	0.64	0.64	0.67	0.72	0.66	0.72	0.63
620100812	0.98	0.84	0.82	0.88	0.91	0.86	0.96	0.90
620101210	0.72	0.66	0.63	0.74	0.79	0.73	0.67	0.66
620103210	0.63	0.49	0.51	0.53	0.50	0.52	0.51	0.51
620103410	3.54	3.53	3.65	3.98	4.07	3.43	3.86	3.84
620103812	0.90	0.71	0.74	0.75	0.78	0.77	0.81	0.76
620105412	0.75	0.70	0.69	0.72	0.74	0.71	0.71	0.65
620155610	0.17	0.16	0.19	0.17	0.15	0.15	0.14	0.14

## Appendix 3.

### Data description: Wind Hazard (speed classified vector data)

These folders contain vector-format files of wind hazard data, classified by return period wind speed values defined in Table 2. These are defined for gust wind speeds at 20, 50, 100, 200, 500, 1000 and 2000 year return period intervals. Data are presented for current climate and for two IPCC climate scenarios (A2 and B1), at eight future time periods (2020 to 2090 at 10-year intervals).

**Table 1: Data fields in each file.**

FIELD NAME	DATA TYPE	DATA DESCRIPTION
FID	Object ID	
Shape	Geometry	Geometry type (polygon)
ID	Double	
CLASS	Short integer	Wind speed site classification, based on return period wind speeds and local site conditions. The value represents the wind speed range. i.e. a value of 10 indicates a site wind speed of between 38 and 40 metres per second.

**Table 2: Wind speed classifications.**

CLASS	WIND SPEED RANGE	CLASS	WIND SPEED RANGE
1	< 22 m/s	10	38 – 40 m/s
2	22 – 24 m/s	11	40 – 42 m/s
3	24 – 26 m/s	12	42 – 44 m/s
4	26 – 28 m/s	13	44 – 46 m/s
5	28 – 30 m/s	14	46 – 48 m/s
6	30 – 32 m/s	15	48 – 50 m/s
7	32 – 34 m/s	16	50 – 52 m/s
8	34 – 36 m/s	17	52 – 54 m/s
9	36 – 38 m/s	18	> 54 m/s

Available datasets (recommended alias):

- Wind speed class: AS1170.2: 20 to 2000 year return period
- Wind speed class: C20C: 1990: 20 to 2000 year return period
- Wind speed class: A2: 2020–2090: 20 to 2000 year return period
- Wind speed class: B1: 2020–2090: 20 to 2000 year return period



## Data description: Wind hazard (AS 4055 classification vector data)

These folders contain vector-format files of wind hazard data, classified by the ultimate limit state wind speed values defined in Table 2.1 of Australian Standard 4055 – *Wind loads for housing* (AS 4055, 2006). These are defined for a 500-year return period gust wind speed.

Data are presented for current climate and for two IPCC climate scenarios (A2 and B1), at eight future time periods (2020 to 2090 at 10-year intervals). Also included are data for the current climate wind hazard, based on analysis of climate simulations of the 20th century, and data based on wind hazard defined by Australian Standard/New Zealand Standard 1170.2–2002 – *Structural design actions Part 2: Wind actions* (AS/NZS 1170.2, 2011).

**Table 1: Data fields.**

FIELD NAME	DATA TYPE	DATA DESCRIPTION
FID	Object ID	
Shape	Geometry	Geometry type (polygon)
ID	Double	
CLASS	Short integer	AS 4055 site classification, based on 500-year return period wind speed and local site conditions. The value represents the non-cyclonic classification. i.e. a value of 2 indicates a site classification of N2 in Table 2.

**Table 2: Wind speed classifications as per AS 4055–2006. Tasmania is in Region A (non-cyclonic) in AS/NZS 1170.2–2011.**

WIND CLASS		DESIGN GUST WIND SPEED ( $V_h$ ) AT HEIGHT ( $h$ ) metre/second	
REGIONS A AND B (NON-CYCLONIC)	REGIONS C AND D (CYCLONIC)	SERVICEABILITY LIMIT STATE ( $V_{h,s}$ )	ULTIMATE LIMIT STATE ( $V_{h,u}$ )
N1	–	26	34
N2	–	26	40
N3	C1	32	50
N4	C2	39	61
N5	C3	47	74
N6	C4	55	86

Available datasets (recommended alias):

- AS4055 class: AS1170.2
- AS4055 class: C20C: 1990
- AS4055 class: A2: 2020 to 2090 in 10-year steps
- AS4055 class: B1: 2020 to 2090 in 10-year steps

## Data description: Wind risk (loss aggregated to Statistical Local Area.[SLA])

These folders contain polygons (shapefiles) of Statistical Local Areas (SLAs). The fields in the shapefile represent risk, expressed in terms of percentage of replacement cost. All results are calculated at the individual building level (i.e. we determine the percentage of damage due to wind gust for each building) and aggregated to SLAs. The annualised loss represents the annual average loss due to severe wind when the average is taken over a very long period of time (e.g. 2000 years). Losses are calculated for two different population projections (Series A and B), two climate scenarios (A2 and B1) and 8 time periods (2020 to 2090 in 10-year steps).

The table below details the contents of each field contained in each shape file.

**Table 1: Data fields in each file**

FIELD NAME	DATA TYPE	DEFINITION
SLA_NAME	String	SLA name
SLA_CODE	Long integer	9 digit SLA identifier
Value_Total	Double	Total replacement value (AU \$) of the residential property. Values are only accurate to the nearest \$1000.
loss_0020	Double	Loss (% replacement value) arising due to a 1-in-20 year event (annual probability of 5%).
loss_0050	Double	Loss (% replacement value) arising due to a 1-in-50 year event (annual probability of 2%).
loss_0100	Double	Loss (% replacement value) arising due to a 1-in-100 year event (annual probability of 1%).
loss_0200	Double	Loss (% replacement value) arising due to a 1-in-200 year event (annual probability of 0.5%).
loss_0500	Double	Loss (% replacement value) arising due to a 1-in-500 year event (annual probability of 0.2%).
loss_1000	Double	Loss (% replacement value) arising due to a 1-in-1000 year event (annual probability of 0.1%).
loss_2000	Double	Loss (% replacement value) arising due to a 1-in-2000 year event (annual probability of 0.05%).
Annualised	Double	Annualised loss (% replacement value) due to severe wind events. This is equivalent to the annual average loss due to severe winds, when taken over a very long period of time (2000 years).

### Available datasets:

- Current: C20C: 1990
- Current: Standard (AS1170.2)
- Series A: A2: 2020 to 2090 in 10-year steps
- Series A: B1: 2020 to 2090 in 10-year steps
- Series B: A2: 2020 to 2090 in 10-year steps
- Series B: B1: 2020 to 2090 in 10-year steps