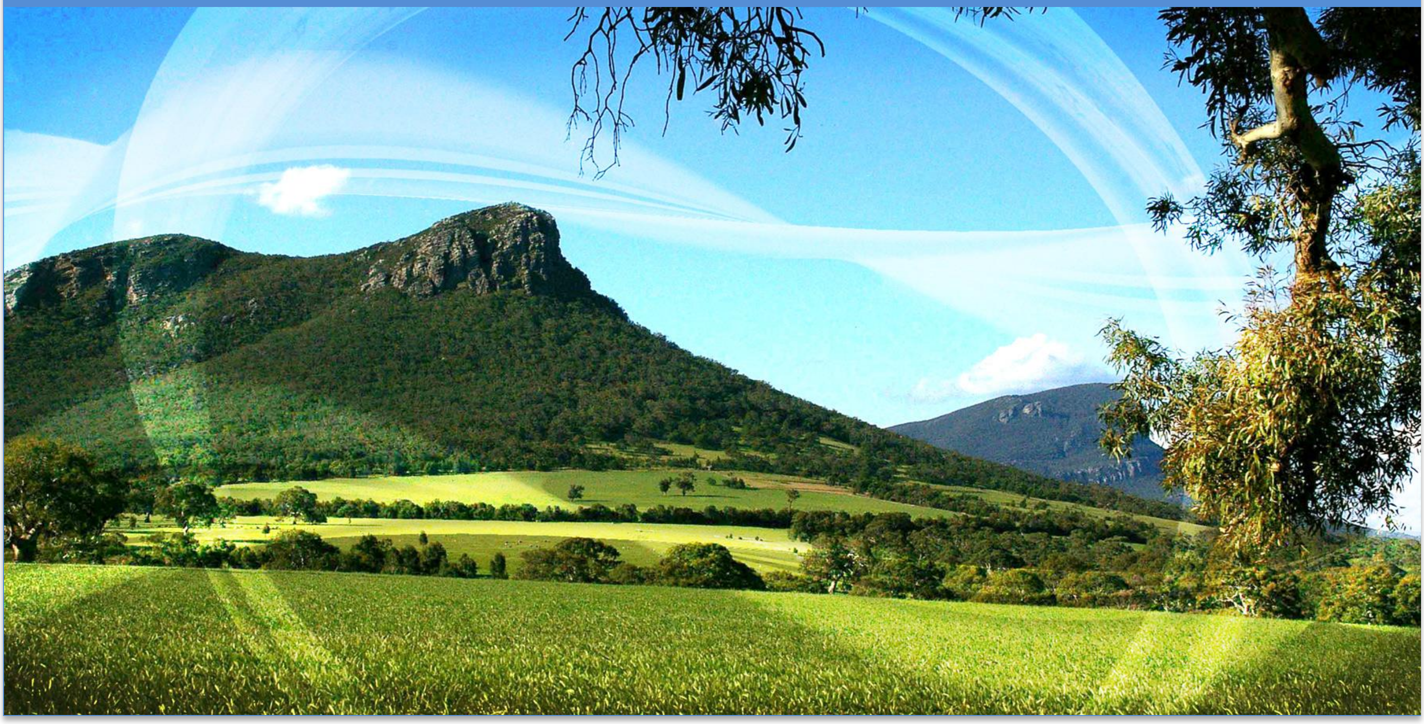
Glenelg Hopkins CMA

GLENELG HOPKINS CMA
CLIMATE CHANGE STRATEGY

Responding to Climate Change in the Glenelg Hopkins Region

2016 - 2023



Australian Government

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Contents

DOCUMENT STRUCTURE

<table>
<tr><th></th><th colspan="2">Chapters</th><th>Overview</th></tr>
<tr><td rowspan="4">Section 1: Developing the strategy</td><td colspan="2">The purpose</td><td>An outline of the aim and purpose of the strategy</td></tr>
<tr><td colspan="2">Strategic relationships</td><td>A summary of the relevant legislation and government policy</td></tr>
<tr><td colspan="2">How the strategy was developed</td><td>An outline of the process used to develop the strategy</td></tr>
<tr><td colspan="2">Planning approaches</td><td>A summary of the adaptation pathways planning approach & the climate ready assessment of RCS objectives</td></tr>
<tr><td rowspan="2">Section 2: Climate Projections</td><td colspan="2">Climate projections</td><td>A summary of global and regional climate projection information</td></tr>
<tr><td colspan="2">Vulnerability</td><td>Detail of the vulnerability modelling, the development process & data used</td></tr>
<tr><td rowspan="4">Section 3: Adaptation</td><td rowspan="4">Vulnerability and pathways mapping for thematic assets:
• Community participation
• Rivers & flood plains
• Wetlands
• Coasts & estuaries
• Marine
• Terrestrial habitat
• Species, populations & communities
• Soil & land</td><td>Impacts</td><td>A summary of the impacts of climate change based on geographic regions, projected global climate change impacts, observed trends & regional data for the Glenelg Hopkins CMA region</td></tr>
<tr><td>Vulnerability modeling</td><td>Vulnerablity maps show change over time for each asset. Vulnerability could not be mapped for all species, populations & communities nor the marine asset</td></tr>
<tr><td>Pathways</td><td>An adaptation pathway for each asset class</td></tr>
<tr><td>RCS objectives</td><td>A climate ready assessment of RCS objectives for each asset</td></tr>
<tr><td rowspan="7">Section 4: Mitigation</td><td colspan="2">Carbon sequestration</td><td>A description of carbon sequestration</td></tr>
<tr><td colspan="2">Emissions reduction fund</td><td>A summary of the Emissions Reduction Fund</td></tr>
<tr><td colspan="2">Blue carbon</td><td>A summary of blue carbon opportunties within the region</td></tr>
<tr><td colspan="2">Revegetation</td><td>Prioritisation of carbon planting activities</td></tr>
<tr><td colspan="2">Benefits and risks</td><td>Detail of benefits & risks associated with carbon plantings</td></tr>
<tr><td colspan="2">Priority landscape modelling</td><td>Mapping to guide the location of carbon planting activities</td></tr>
<tr><td colspan="2">Priority landscapes for climate change mitigation action</td><td>Identification of priority areas for protection and enhancement activities</td></tr>
<tr><td rowspan="2">Section 5: Implementation</td><td colspan="2">Policy statements & strategic initiatives</td><td>Policy statements and strategic initiatives for implementation</td></tr>
<tr><td colspan="2">Monitoring, evaluation and reporting</td><td>Details of the monitoring, evaluation & reporting process & how it contributes to adaptive management & adaptation planning</td></tr>
</table>

EXECUTIVE SUMMARY

The Glenelg Hopkins Strategy for Climate Change will be used to inform regional planning through the identification of priorities for adaptation and mitigation under a changing climate. This strategy was developed in consultation with the Glenelg Hopkins CMA Community Advisory Group and through a series of targeted workshops with agencies, regional experts and community members.

The challenge of climate change is fundamentally different from all other threats to biodiversity and ecosystem function. It requires a shift in the way natural resource management (NRM) objectives are developed. Despite the overall trend of a hotter and drier climate being clear there are uncertainties in climate change projections and their application at a regional level. These uncertainties are compounded when identifying impacts at local scales because of complexities in ecological interactions and interdependencies. Glenelg Hopkins CMA has developed a set of policy statements that move away from defining static objectives to ones that are more appropriate under a changing climate, and that allow planning for a range of different future states. These statements form the basis of the CMA's adaptive approach to regional planning under a changing climate and will assist the CMA to:

- provide regional leadership and set the example of best practice management of natural resources under climate change
- manage for resilience and transformation
- manage adaptively for multiple scenarios and for multiple possible futures
- keep up to date with research and undertake long-term monitoring of species, communities and ecological processes.

The impacts of climate change

It is clear that climate change will have significant impacts on species and ecosystems in Australia. For the Glenelg Hopkins region, climate change projections indicate that increasingly hotter and drier conditions can be expected. Temperatures are expected to increase in all seasons with a greater number of hot days and fewer very cold days overall. By 2090 the projected temperature increase of up to 4.0 ºC will have significant impacts on the region's terrestrial habitats and species, populations and communities. Changes in the geographic range of both flora and fauna species may result in altered community structure and function. Although it is difficult to predict individual species' responses to a changing climate due to complexity in ecological interactions, it is likely that the timing of life cycle processes such as migration, flowering and breeding will be altered. The ability of flora and fauna species to move through the landscape will also dictate their survival. Ultimately the change in climate will result in a decrease in the region's biodiversity and a change in the current location of species and communities.

A decrease in winter rainfall of up to 30 per cent by 2090 and an increase in the intensity of extreme rainfall events are expected across the Glenelg Hopkins region. Soil and land assets are likely to experience a decrease in groundcover and an increase in the likelihood of erosion events. Less rainfall and greater temperatures are likely to cause a reduction in pasture production and persistence. This may have implications for the region's feed management systems, with a potentially greater dependence on cool season production, grain feeding and stored fodder. With less rainfall the Glenelg Hopkins catchment is also likely to become increasingly suitable for cropping. This land use change and subsequent increasing pressures from production may have implications for remnant vegetation and wetland protection.

Rivers, floodplains and wetlands would be greatly impacted by the reduction in rainfall and subsequent runoff and stream inflow. Rivers and wetlands that rely on direct precipitation will be most affected. The region's wetlands are likely to undergo a variety of changes such as reduction in size, conversion to dry land or a shift in wetland type. Despite wetlands being very vulnerable to climate change, they are by nature a resilient ecosystem. The protection and enhancement of wetlands will become increasingly important due to their carbon sequestration potential and ability to act as 'stepping stones' for biodiversity through the catchment. Rivers are also critical for maintaining connectivity through the landscape. Riparian vegetation and refuge areas will become increasingly important with reduced stream inflow and more hot days. A reduction in water availability and possible increase in demand may intensify pressure on the region's water resources, including its rivers and groundwater.

Sea surface temperatures are likely to increase by 1.6–3.4 ºC by 2090, causing significant changes to coastal, estuarine and marine assets. Large increases in temperature will have significant impacts on the current geographical ranges of species. Effects are already evident with a southward movement in the range of macroalgaes, with likely impacts on the many species they support. Tropical pest species are expected to extend their habitat range further south, placing greater pressure on the region's marine areas. An increase in sea level of 0.39 – 0.89 metres (m) by 2090 will increase pressure on the coast and estuaries. Impacts such as coastal erosion and inundation will be more likely, causing habitat loss and infrastructure damage.

Adapting to and mitigating climate change

While the magnitude of climate change is more widely recognised and acknowledged in science and policy, there remains a gap between recommendations for adaptive management approaches and resilience building at a regional scale. Glenelg Hopkins CMA is committed to adopting a long-term, adaptive approach to NRM planning under climate change. This strategy aims to fill the identified gaps in regional planning by applying adaptive planning processes to update the CMA's policies and strategic priorities.

Effective adaptation to climate change requires building on past and current successful NRM programs. The current programs for managing natural resources contribute significantly to adaptation by improving ecosystem resilience, increasing groundcover, protecting existing assets and enhancing habitat connectivity. The continued establishment of priorities that focus on ecological function and ecosystem services will be the key to achieving effective on-ground action into the future. Glenelg Hopkins CMA aims to build natural asset resilience and adaptive capacity through adopting the four policy statements and implementing a range of strategic initiatives for each asset, as detailed in Table 12. Natural resource managers have a significant role to play in mitigating climate change through the protection of existing carbon stocks and guiding further carbon sequestration efforts. Large quantities of carbon are stored in soils and vegetation of the Glenelg Hopkins region. Mitigating the loss of these carbon stores will reduce the amount of carbon entering the atmosphere and further exacerbating climate change. In addition to sequestering carbon in vegetation and terrestrial soils, there is significant opportunity within the region to maximise the estimated 34.4 Million tonnes (Mt) of wetland carbon stores. A national assessment of the opportunities for reducing carbon emissions in the land sector found that reforestation and agricultural practice change had the potential to abate 50 Mt CO_2 of emissions across Australia[1].

Responding to climate change in the Glenelg Hopkins region requires increasing the resilience of the natural environment to adverse impacts, maximising the capacity of ecosystems to adapt to change, and maximising the storage of carbon in the landscape consistent with continued productive agricultural enterprises. Fortunately, the actions that will be most effective in achieving these objectives are consistent with best practice approaches that are advocated in the CMA's present strategies. The following strategic priorities will be pursued to best position the region to thrive in the face of climate change:

- carbon planting projects that improve landscape connectivity and resilience, and wildlife corridors, ensuring multiple benefits for the environment
- protection and improvement of blue carbon (wetland) habitats
- increasing the resilience of agricultural land by fostering soil health and increasing groundcover, and improving the productivity of degraded land
- carbon planting projects within high value agricultural areas with positive impacts for adaptation and production.

Landscape scale priorities

A landscape prioritisation process has been completed to identify the opportunities for carbon sequestration and improve ecosystem resilience. This process has considered the current condition of the region's vegetation and wetlands, their strategic biodiversity value and their carbon sequestration potential. Priority landscapes for biodiverse carbon plantings that present the greatest potential to increase landscape resilience and connectivity as well as carbon sequestration include:

- existing parks and reserves (public land), and areas of remnant vegetation abutting these locations
- the areas connecting the Glenelg River through Dergholm and east to the Grampians National Park and further east to the Pyrenees Ranges
- riparian areas
- wetlands and wetland complexes
- coastal areas including estuaries and coastal saltmarsh habitats.

These areas are shown in Figure 1. In protecting and enhancing all identified priority terrestrial vegetation there is the potential to sequester 52.7 M tonnes/year CO_2 across the region. Ensuring the maintenance of current carbon stored within wetlands will protect an additional 34.4 M tonnes CO_2. Although public land isn't directly considered within the carbon calculations, it is an important carbon store and provides significant biodiversity values.

This strategy highlights the importance of protecting and enhancing wetlands within the Glenelg Hopkins region due to their carbon sequestration potential and ability to act as carbon sinks. It also highlights the importance of building ecological resilience to give ecosystems the best possible chance to adapt under a changing climate and identifies a range of management options to achieve this.

The Glenelg Hopkins region is one of the most productive regions for agriculture in Australia, with many areas of the catchment supporting high value agricultural production. These areas are considered less suitable for large scale carbon planting. However, wetland protection and enhancement, the creation of shelterbelts and the protection of remnant vegetation and paddock trees will be encouraged in these areas.

If not implemented carefully, carbon planting projects could have negative impacts on the landscape including changes to local hydrology and fire regimes, and reduced biodiversity. It will be important for local assessments to be undertaken before implementing carbon plantings to evaluate potential challenges, mitigation and environmental gains.

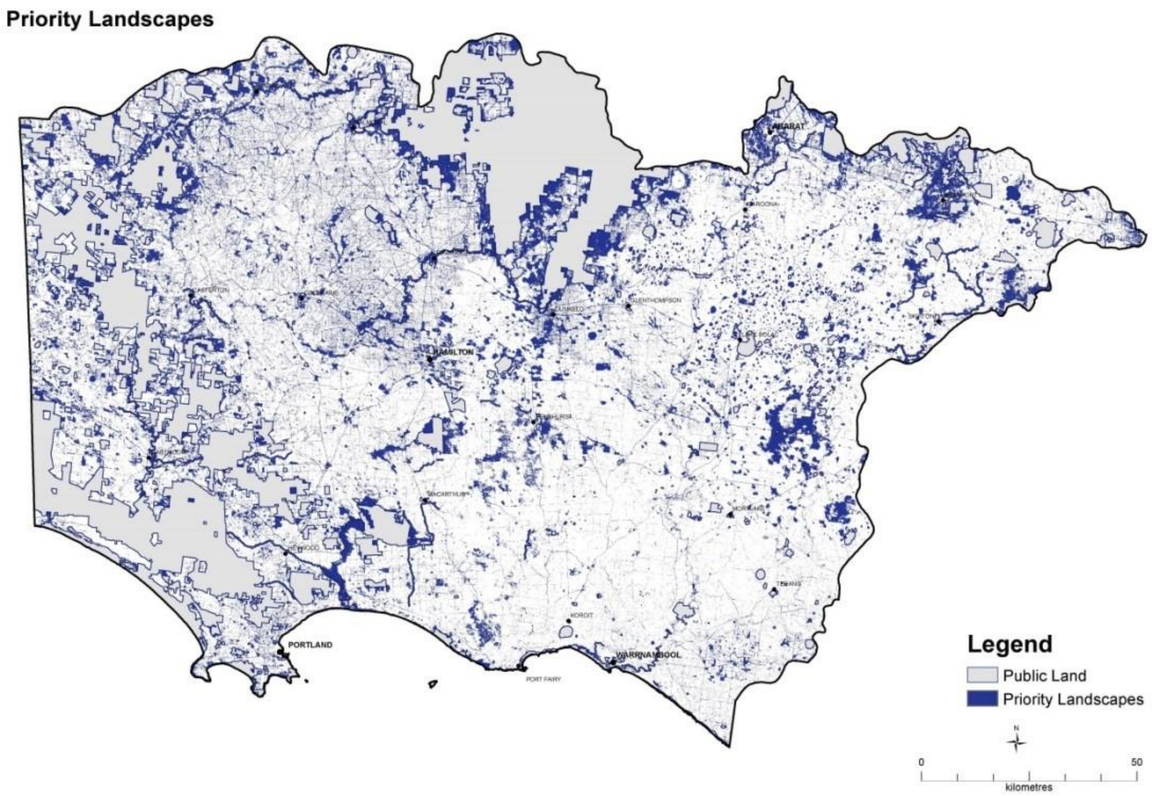


Figure 1: Priority landscapes for climate change mitigation action

Putting the strategy to work

A number of strategic initiatives have been proposed as the most effective way of providing a response to climate change for natural resource management in the Glenelg Hopkins region. These cover the most important directions for the major resource asset classes in the Regional Catchment Strategy (RCS), and these will be integrated into the the RCS when it is next updated. Their implementation will be monitored and updated as more information becomes available on the impacts of climate change and the effectiveness of the region’s response to it.

SECTION 1

DEVELOPING THE STRATEGY

THE PURPOSE

This strategy has been developed as a complementary document to the Glenelg Hopkins Regional Catchment Strategy 2013–2019 (RCS). This strategy will inform the development of the next RCS in 2019 and become a supporting technical resource. Implementation of the Strategy will be coordinated by Glenelg Hopkins CMA.

The 50-year vision for the Glenelg Hopkins catchment is:

'Achieving a healthy and sustainable relationship between the natural environment and the community's use of land and water resources.'

Within the RCS, climate change is recognised as presenting a major challenge to achieving this goal. Glenelg Hopkins CMA has committed to undertaking action to manage and reduce the impact of climate change through building resilience and supporting adaptation[2].

This strategy is intended to enable the integration of mitigation and adaptation strategies into current and future programs undertaken in the region. The focus is on natural resources while recognising that the social and ecological systems of the Glenelg Hopkins region are intrinsically linked through the use of natural systems and the services that they provide. The strategy will be used to inform regional planning through the identification of policy statements, strategic initiatives and adaptation planning approaches.

The best available research and information has been used to prioritise landscapes for carbon planting and to identify strategic initiatives for adaptation. Tools and information are provided to support a shift away from viewing climate change as simply another threat to conservation and towards recognising the true implications and actions required to build resilience and adaptive capacity.

STRATEGIC RELATIONSHIP

The Glenelg Hopkins CMA Climate Change Strategy complements the RCS by providing strategic direction and guidance on the integration of climate change into management of the region's natural resources. It will also inform the development of sub-strategies and the next update of the RCS, which is expected to commence in 2019 (see Figure 2). The strategic initiatives identified complement the RCS objectives and aim to fill identified gaps when considering a changing climate.

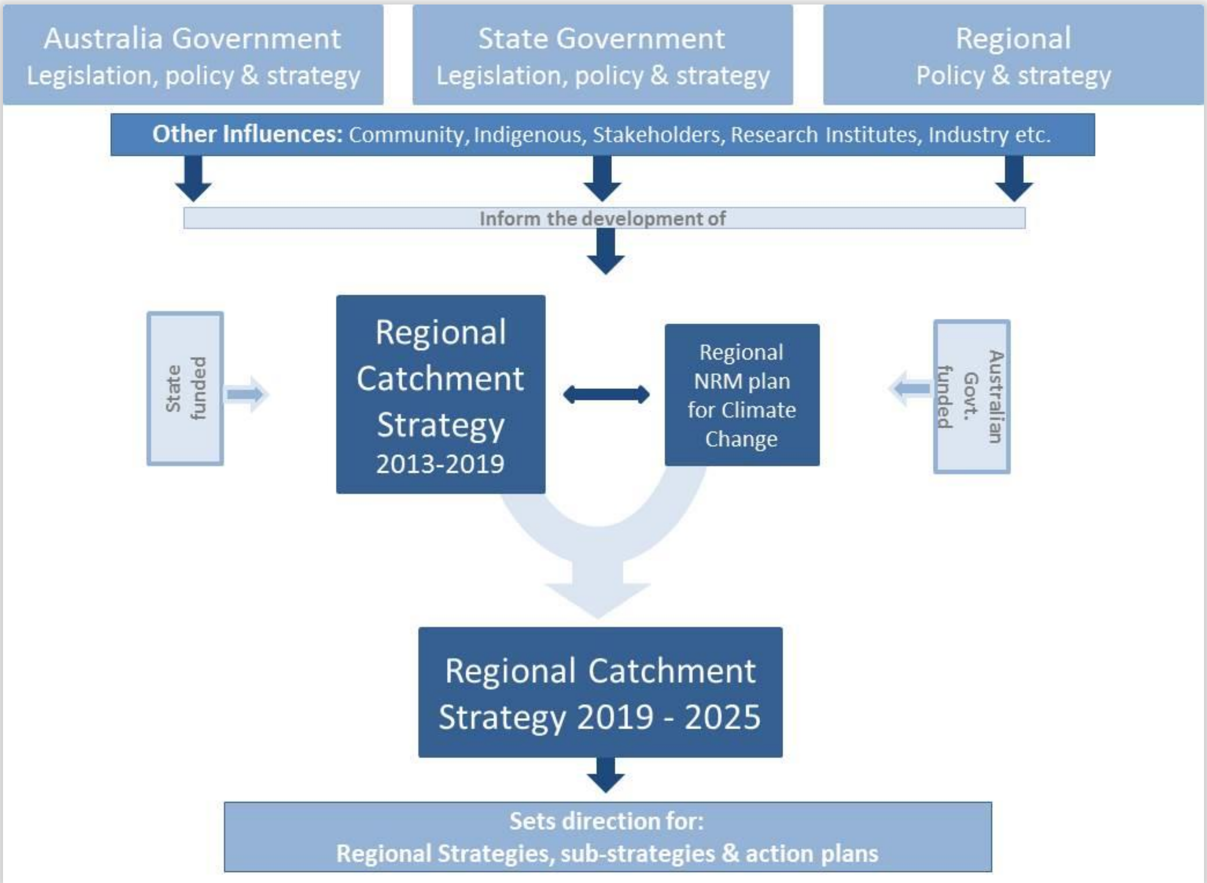


Figure 2: Policy context

Victorian Government: Climate Change Act 2010

The *Climate Change Act 2010* (Vic)[3] is a framework for the Victorian Government to respond to climate change (covering both mitigation and adaptation) within the context of national policy. The Act commits the Victorian Government to develop a Climate Change Adaptation Plan, with updates every four years. The first plan was released on 19 March 2013[4]. Each update to the plan must include a report on the implementation and effectiveness of the previous plan. The Act also requires decision makers to take climate change into account through a number of key pieces of legislation relevant to the activities of the CMA and other NRM agencies. These include the *Victorian Catchment and Land Protection Act 1994, Coastal Management Act 1995, Environment Protection Act 1970, Flora and Fauna Guarantee Act 1988 and Water Act 1989*.

HOW WAS THE STRATEGY DEVELOPED?

The development of this strategy was funded through the Regional Natural Resource Management Planning for Climate Change Fund. The program structure for the development of this document is outlined in Figure 3.

The program is comprised of two streams: Stream 1, which funded the development of the strategy, and Stream 2, which funded the provision of data for incorporation into this strategy via two separate elements.

Element 1 of Stream 2 is being delivered by the Bureau of Meteorology and CSIRO in the form of climate projections downscaled from the International Panel on Climate Change (IPCC) global projections data.

Element 2 of Stream 2 is a cooperative project with CMAs to translate the latest research on climate change adaptation and synthesise it into practical guidelines for adaptation planning.

The resources produced by elements 1 and 2 of Stream 2 were used to inform the strategy. The information provided is the best currently available; however, it may require updating in future.

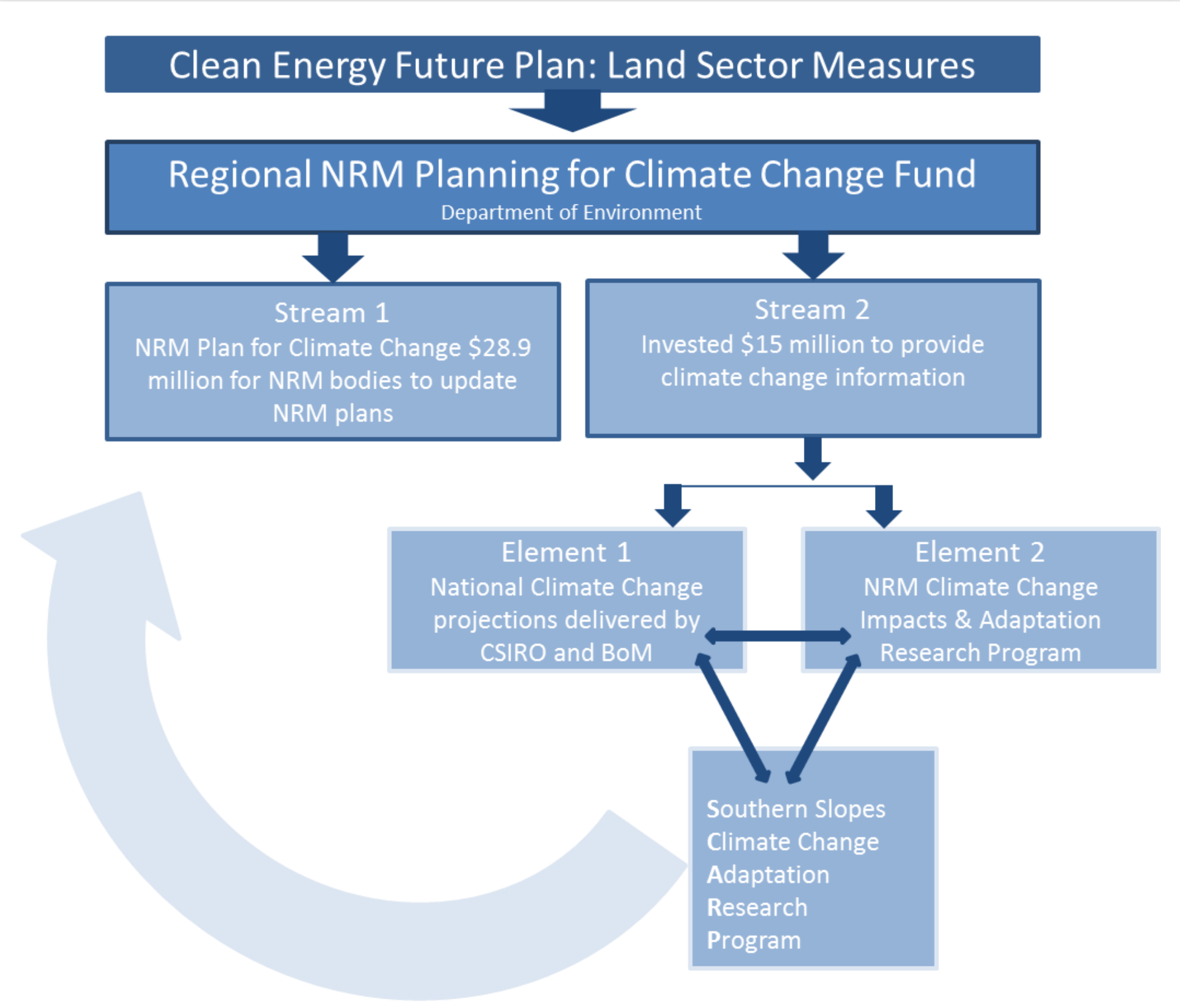


Figure 3: Funding structure

Stakeholder engagement

In developing the strategy, a targeted engagement approach was used. Engagement was undertaken across several sectors including community, Landcare, regional experts, agencies and non-government organisations.

The Glenelg Hopkins CMA Community Advisory Group provides advice to the CMA on the development of regional strategies and plans as well as emerging community concerns, issues, and threats that impact NRM assets across the region. The Advisory Group provided advice through a series of workshops on the development of the overarching adaptation principles as well as drafts of the document. The Advisory Group includes representatives from the community, industry groups, NRM partner agencies, such as the Victorian Department of Environment, Land, Water and Planning (DELWP), Department of Economic Development, Jobs, Transport and Resources (DEDJTR), Parks Victoria and local government.

Community input into the development of the strategy was also obtained through a one-month public consultation period in October and November 2015, and a series of workshops held across the region.

PLANNING APROACHES

There are a variety of approaches to planning for climate change. Two of the most recent and innovative are the 'climate ready' and 'pathways' approaches, and both have been used to guide the development of this strategy. These two approaches are complementary, and in association with the identified policy statements, provide a test for the appropriateness of future plans and actions under climate change.

Planning for climate change requires an adaptive approach[5]. This is because while the overall trend of a hotter and drier climate is clear, there are uncertainties in climate change projections and their downscaling to a regional level. These uncertainties are compounded when specifying impacts of climate change at local scales, due to the complexity of ecological interactions and interdependencies[6]. Adopting this approach enables planning for immediate action and best practice, and provides a manner in which to plan longer term for options across a range of possible futures[7].

Each asset is explored for the potential impacts of climate change and the subsequent consequences for the Glenelg Hopkins region. Vulnerability mapping for each asset provides a visual representation of the level of vulnerability to the changing climate over time. This information is used in the development of adaptation pathways that identify the potential immediate and long-term adaptation actions. The suite of information for each asset, in addition to the 'climate ready' propositions, provides the basis for assessment of the robustness of current RCS objectives under a changing climate. The RCS assets addressed include community participation, rivers and floodplains, wetlands, coasts and estuaries, marine, terrestrial habitat, species, populations and communities, and soil and land.

Managing for multiple possible futures: adaptation pathways

'Pathways planning' provides an intuitive and practical approach to planning for climate change in NRM. It integrates strategic and adaptive management that embraces change and uncertainty as normal parts of planning and implementation. It also recognises that change can happen both incrementally and suddenly as a result of unprecedented events (e.g. major fires, floods, storm surges) and that these changes can not only result in loss, but in innovation and renewal if the region is prepared for them.

The adaptation pathways approach ultimately allows organisations or communities to develop a suite of measures that, taken together, can achieve positive NRM outcomes in the face of a changing climate. It acknowledges that learning occurs by doing and so is flexible enough to be adjusted as knowledge, information, experience, values, and systems change. An adaptation pathways approach is itself adaptable to different management contexts, and allows organisations to plan for and implement measures to address immediate priorities (e.g. habitat loss, inappropriate farming practices or fire regimes, or management of invasive species). At the same time it examines how robust these measures will be across a range of possible futures.

Importantly for a strategy such as this, a pathways approach is underpinned by meaningful dialogue among stakeholders. This dialogue explores current management actions and how they may need to change to remain relevant under a range of future scenarios. It allows communities and organisations to identify what can be done now, and what preparatory measures may be needed for longer term changes to management, policy or practice.

Actions considered in climate change planning must be tested for adaptation benefit, relevance under climate change scenarios and time frames, potential for maladaptation, and climate readiness[8]. Actions can be grouped relating to contribution to building the resilience of an existing asset, the possibility of the asset requiring transformation, and/or the transition between the two phases.

A pathways approach encourages organisations and communities to consider different options in advance, so a change in direction can be made if required. Each pathway map identifies adaptation options relevant to an asset. A pathway shows how a single action plays out over time. Pathway maps are not meant to imply that all options should be pursued, rather that there are various options to be considered and potentially prepared for in the long term, depending on the impacts of climate change as they play out over time. An example pathway and a key to the symbols used in the pathways maps are provided in Figure 5.

Pathways have been developed for all asset classes identified in the RCS and are shown in detail in Section 3 of this strategy.

Pathway Example and Key

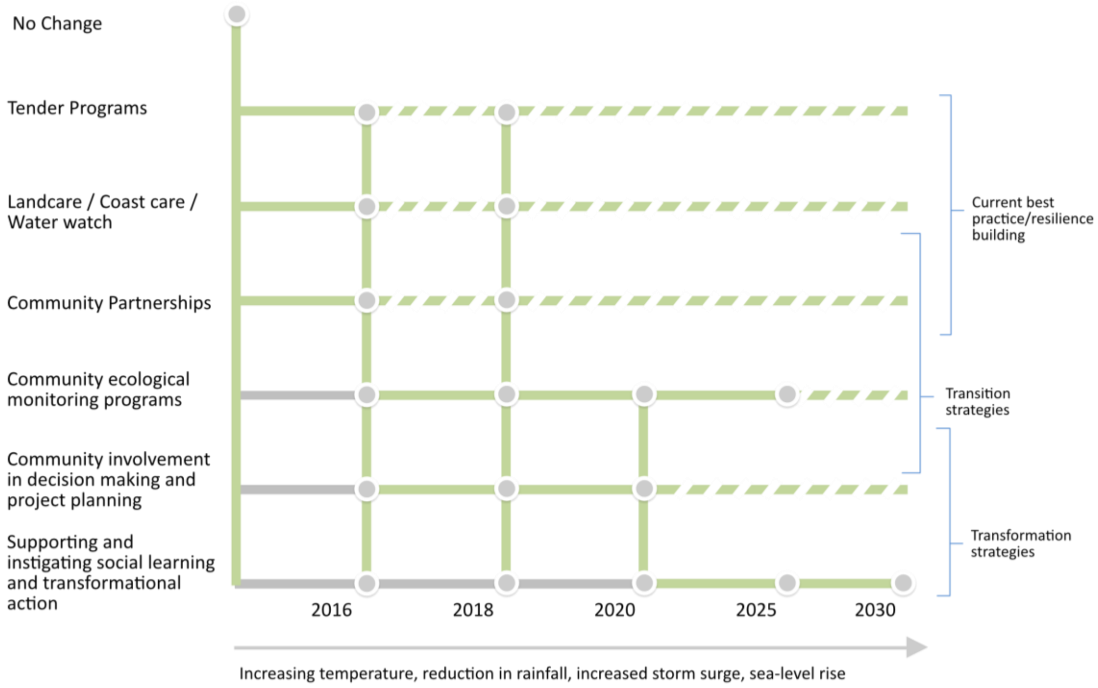


Figure 4: An example adaptation pathway

The following key is provided to assist with interpretation of adaptation pathway maps:

A solid dark green line indicates the time period over which an action is most relevant

A solid light grey line indicates the time before an action is fully implemented in which preparation is required

A dashed green line indicated the time in which an action continues to contribute to adaption in part

Circles indicate decision points where implementation of a particular action needs to begin in response to change

Current best practice/resilience building – Activities that are accepted as being current and most effective. These practices are considered to increase the ability to recover or re-organise after disturbance.

Transition strategies – Activities that support the process of moving from one state or condition to another. This can either be in terms of an ecosystem or management practice.

Transformation strategies – The result of completed change to a new state, condition or practice. These strategies may currently be challenging to conceive and require significant research and preparation.

There is no priority in the order that actions are listed.

The x-axis represents the general trend in changing climate represented by the standard time frames used in projection scenarios and should be read as indicative of change rather than as precise times.

It should also be noted that change in time is not the only factor to be considered. Socio-political changes and increased knowledge of systems will also heavily influence the appropriateness of actions over time.

Figure 5: Key to interpreting adaptation pathway maps

Climate ready assessment of RCS objectives

The climate ready approach provides a new way of framing NRM objectives. The approach moves away from the development of static objectives to those that are more appropriate under a changing climate[9]. It results in objectives that differentiate between the action required under significant climate change and those in stationary climates. The purpose of the climate ready approach is to ensure NRM objectives are effective and achievable under a changing climate[10].

Under significant levels of climate change many of the current approaches to NRM will become increasingly difficult and ineffective (e.g. maintaining vegetation community types in their current locations). The challenge of climate change is fundamentally different from all other threats to biodiversity and ecosystem function, and requires a change in the way NRM objectives are developed [11].

Using key insights from the scientific literature on climate change and biodiversity, three adaptation propositions have been developed to manage biodiversity under a changing climate[12]:

- Conservation strategies must accommodate significant amounts of ecological change and the likelihood of significant losses in biodiversity.
- Strategies must remain relevant and feasible under a range of possible future trajectories of ecological change.
- Strategies must seek to conserve the multiple different dimensions of biodiversity that are experienced and valued by society.

These propositions have been used to assess the existing objectives within the RCS. Tables summarising the results of each 'climate ready' assessment are provided in Section 3 of the strategy for each asset theme. The assessment will be used to inform the next update of the RCS, ensuring that all future objectives are climate ready. In the interim, assessments will complement the objectives within the RCS and be used to ensure that the practices of the CMA continue to contribute to adaptation and mitigation in the best way possible.

SECTION 2

CLIMATE PROJECTIONS AND VULNERABILITY

CLIMATE PROJECTIONS

Global Trends and Projections

If current trends continue, global surface temperature change will exceed 2 °C by the end of the century and will continue to rise beyond 2100[13]. Nearly all countries around the world have agreed to limit the rise in global temperature to 2 °C or less compared with the pre-industrial level. Above a rise of 2 °C, the risks to human societies are considered unacceptably high[14]. However achieving this relies on effective, concerted action globally and this has not yet been clearly demonstrated to be occurring or effective.

According to the latest International Panel on Climate Change (IPCC) report[15] the rate of sea level rise since the mid-nineteenth century has been larger than the mean rate during the previous two millennia. Over the period 1901–2010, global mean sea level rose by approximately 0.19 m. Global mean sea level will continue to rise, with the rate of rise likely to exceed previous rises due to increased ocean warming and increased loss of mass from glaciers and ice sheets[16].

Recent Trends in Climate Change

Surface air temperatures have been increasing since records began in 1910 and particularly since 1960. Between 1910 and 2013, the average daily maximum temperatures in the Glenelg Hopkins region have increased by 1–1.1 °C. Daily minimum temperatures have increased by between 0.6–0.7 °C[17].

During the last decade the average annual number of days over 30 °C increased by three days, as did the number of days over 35 °C (by two days). However, unlike other regions in Victoria, the average number of frosts actually increased, by three days, and the number of cold nights (minimum temperature below 5 °C) increased by four per year. This may be a result of changes in cloud cover associated with the millennium drought[18].

There has also been a decline in the region's rainfall since the mid-1970s[19]. There were wet years in the 1950s and 1970s followed by the millennium drought of the 1990s and 2000s. Seasonal trends in rainfall from 1901 to 2012 indicate small changes of less than 5 mm/decade. In general there was an increase in winter, spring and summer rainfall and a decrease in autumn rain. However, from 1960 to 2012 there was a consistent decrease in winter and spring rainfall[20].

These historical trends, model simulations of the climate response to greenhouse gas emissions and knowledge of the climate system formed the basis for the regional climate change projections[21]. The climate projections are not a forecast of the future climate. However, they do show plausible climate system responses to given greenhouse gas emission scenarios[22].

Regional Climate Change Projections

Current projections for climate change for the Glenelg Hopkins region were prepared by CSIRO and the Australian Bureau of Meteorology in 2012–2014. Projections are based on scenarios that calculate emissions growth through to the year 2100, compared with the 1986–2005 levels. Further information about the climate scenarios, climate stressors and timeframes is detailed in Appendix 1.

Key projections for the region are listed below[23]:

- average temperatures will continue to increase by 1.1–4.0 °C by 2030 in all scenarios
- more hot days and warm spells, and fewer frosts
- up to 15% less rainfall in the cool season by 2090, but changes to summer rainfall are less clear
- increased intensity of extreme daily rainfall events
- mean sea level will continue to rise between 0.39 and 0.89 m by 2090, and the height of extreme sea level events will also increase
- a harsher fire-weather climate
- natural climate variability will either enhance or mask long-term trends from year to year, particularly in the near future, and for rainfall.

VULNERABILITY

Vulnerability of Natural Assets

CMAs and other regional NRM bodies will be required to respond to an increasing number of natural resource dilemmas arising from climate vulnerability and change, and its impacts on key assets identified in the Regional Catchment Strategy.

The term 'vulnerability' has been adopted to best describe the impact of change and the sensitivity of an asset. The IPCC[24] describes vulnerability as a function of impact and adaptive capacity and 'the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes'.

In the context of this strategy, vulnerability is defined as a 'measure of possible harm'[25]. In this case, harm to the environment would include such things as:

- a loss of habitat or species diversity
- disruption to food webs
- reduction in ecosystem services
- loss of ecosystem resilience and the capacity to bounce back from stresses
- reduced water quantity or quality
- an increase in habitat fragmentation.

The vulnerability of the RCS assets over 2050, 2070 and 2090 time periods are explored in Section 3 of the document.

Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity. The components of exposure, sensitivity and adaptive capacity and their relationship to vulnerability are illustrated in Figure 6[26].

The following working definitions of exposure, sensitivity and adaptive capacity are provided in an effort to achieve a consistent understanding and interpretation[1]:

Exposure relates to the influences or stimuli that impact on a system. It is a measure of the predicted changes in the climate for the future scenario assessed. It includes both direct stressors (such as increased temperature) and indirect stressors or related events (such as increased frequency of bushfire).

Sensitivity reflects the responsiveness of a system to climatic stressors or influences, and the degree to which changes in climate might affect that system in its current form. Sensitive systems are highly responsive to climate and can be significantly affected by small changes in climate.

Adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. The adaptive capacity of a system or society describes its ability to modify its characteristics or behaviour so as to cope better with changes in external conditions. The more adaptive a system, the less vulnerable it is. It is also defined as the property of a system to adjust its characteristics or behaviour in order to expand its coping range under existing climate variability or future climate conditions. For the purposes of this assessment, adaptive capacity is the ability of an asset to adjust to climate stressors based on its current state, which may vary from pristine to degraded.

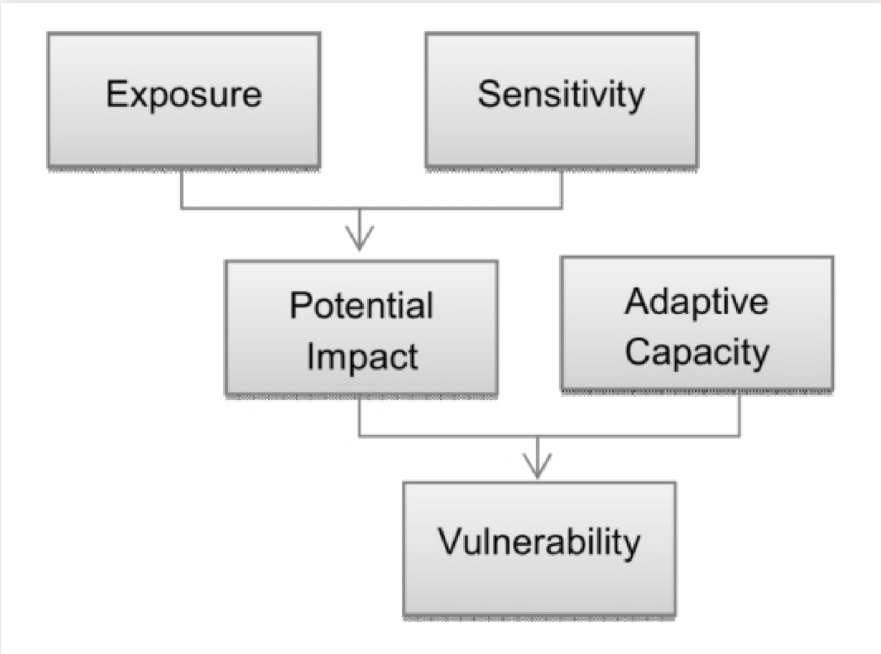


Figure 6: Conceptual framework used to develop a measure of vulnerability under climate change

[1] These definitions are based on those provided in Guidelines For Developing a Climate Change Adaptation Plan and Undertaking an Integrated Climate Change Vulnerability Assessment, November 2012, Local Government Association of South Australia.

Climate Data

The specific climate data provided by CSIRO for this project includes projected climate changes based on global climate models judged to perform well over Australia.

These interim projections are derived from global climate models from the Climate Model Intercomparison Project Phase 5 (CMIP5). They take the form of projected 20-year average changes relative to the 1986–2005 model averages. This data is underpinned by Climate Change in Australia: Projections for Australia's NRM Regions Technical Report.

The data made available has been provided with a native grid resolution of ~135 km. The data includes:

- historical climatology 1986–2005
- future climatologies 2021–2040 (2030), 2041–2060 (2050), 2061–2080 (2070), 2080–2099 (2090)
- change (absolute) – future climate relative to 1986–2005
- climate variables – temperature minimums (Tmin), temperature maximums (Tmax,), precipitation

Data Inputs and Availability

The vulnerability of assets has been determined through a process of assessing the exposure, sensitivity and adaptive capacity of natural assets. A detailed description of the inputs and criteria considered in the development of the vulnerability modelling for each asset is provided in Appendix 2. The maps produced for each asset class are presented in Section 3 of the strategy. A detailed analysis is not presented here as the maps are used to inform the development of landscape scale adaptation pathways for long-term planning. The maps are also available on the South West Climate Change Web Portal and finer scale analysis will be used in the developed of future sub-strategies and plans.

Vulnerability modelling may also be rerun as additional data becomes available. Any updates will also be made available through the South West Climate Change Web Portal.

Vin Gannon

SECTION 3

ADAPTATION

ADAPTATION

This section describes the potential impacts of the changing climate on the regions assets. The asset vulnerability to climate change over time is illustrated in a series of maps at 20-year intervals from 2050 through to 2090.

The impact assessment and vulnerability maps were used to develop an adaptation pathway for each asset theme that explores adaptation issues and potential implementation options. The pathways are not intended as an action plan, but to inform the CMA's strategic initiatives and explore potential future options. A summary of the CMA's strategic initiatives is provided in Table 12.

To facilitate the integration of this strategy into the RCS, and the development of the next RCS, the RCS objectives have been assessed for their appropriateness under a changing climate. The assessment determines whether the objectives are considered climate ready.

Vin Gannon

COMMUNITY PARTICIPATION

Although the adaptation pathway for each of the other assets attempts to address the need for transformation within ecological and agricultural systems, any transformation fundamentally depends on related social systems, including economic and political systems. Glenelg Hopkins CMA has an important and essential role to play in building the capacity of local and regional communities in adapting to climate change.

The Glenelg Hopkins community plays an integral role in the delivery of natural resource management actions and the maintenance and improvement of natural assets. The key to achieving the objectives outlined in the RCS and within this document will be to foster a strong regional identity and connection with the environment. An important part of adaptation and transformation is making the connection between historical actions and present day environmental issues[27]. Programs focused on cultural heritage, culturally sustainable development and Indigenous Ecological Knowledge will play a key role in regional adaptation, improving partnerships and outcomes for communities within the region.

The RCS recognises that there is already a strong community commitment to improve natural resource outcomes across the region. Although more can be done to raise awareness and to support a transition towards a community that is more fully connected with the environment. There is also an opportunity to increase the understanding of the role of ecosystem processes and the social and financial importance of functioning ecosystems. Increasing uptake in partnership projects, Landcare and participation at community forums and field days will contribute to this. However, the long-term goal is to develop programs and processes that allow not just for the involvement of communities, but for true collaboration and empowerment of communities. Through adaptive governance, building resilience, and allowing and encouraging social learning, Glenelg Hopkins CMA can play a leading role in the adaptation and transformation of the region.

Adaptation Planning

The development of an adaptation pathway for community participation focused on supporting community involvement in NRM through partnerships and collaboration. The pathway forms the foundation for achieving improved NRM across the region.

A list of measures for community participation was completed. Measures were assessed for their adaptation benefit, potential for maladaptation and relevance over time are shown in Table 30 of Appendix 3.

Adaptation Pathway: Community Participation

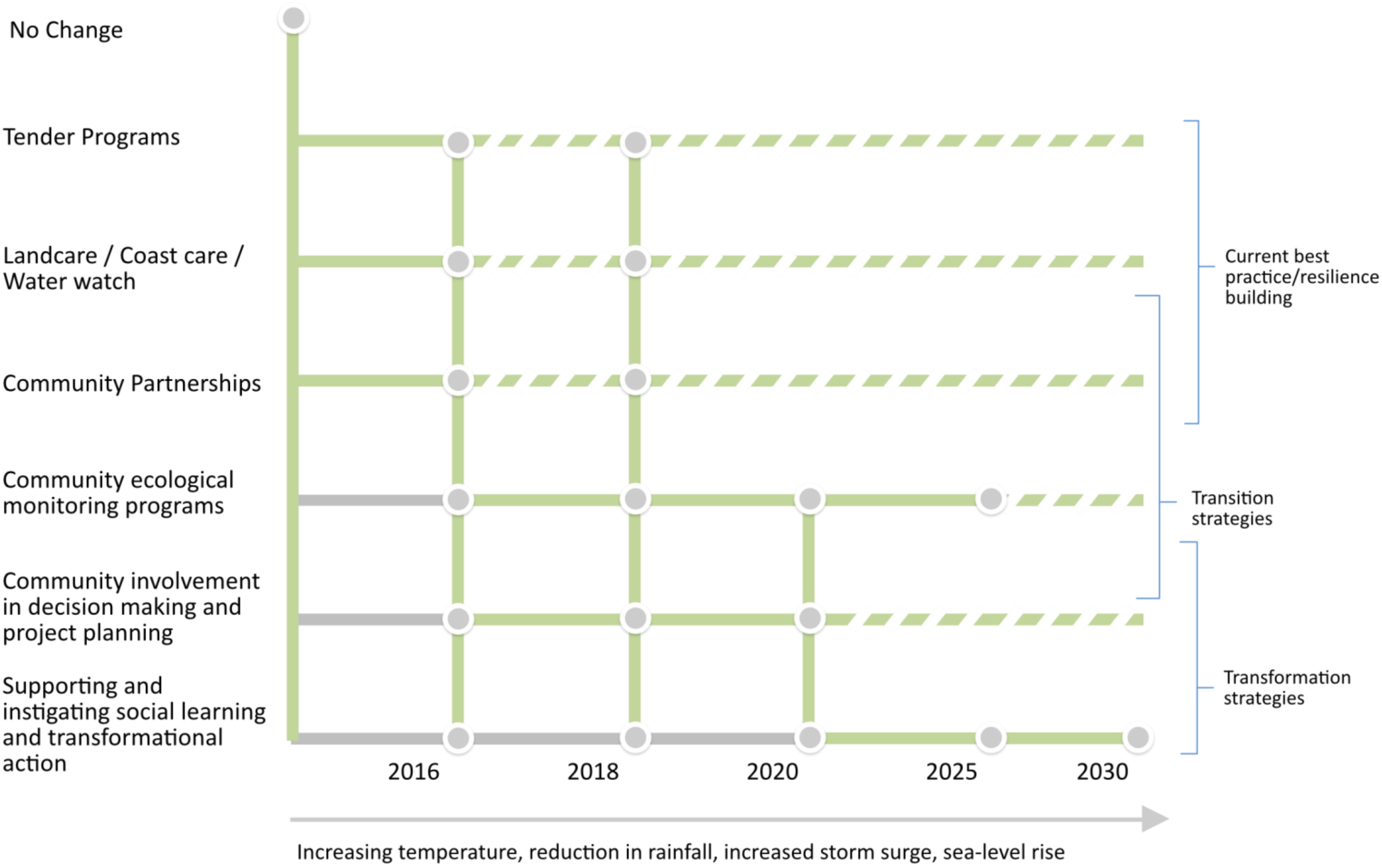


Figure 7: Adaptation pathway for community participation

Strategic Direction

Glenelg Hopkins CMA will pursue partnerships and project opportunities that facilitate community participation in NRM. Current resilience building activities will remain relevant into the future, although more effort will be required to prepare and engage community in climate adaptation or mitigation action.


James Pevitt

A particular focus will be on projects that provide opportunities for social learning and improve community awareness of ecosystem processes, climate change and the importance of protecting and improving connectivity and biodiversity. The transformational activities identified aim to facilitate an informed, active and resilient regional community.

In ensuring an adaptive approach to planning, the CMA will integrate future available climate data and information into regional planning.

Strategic Initiatives

- Support community participation in NRM activities and decision making
- Increase community awareness of ecosystem processes, climate change and the importance of protecting and improving biodiversity and landscape connectivity
- Integrate best available climate change information and data into regional planning
- Integrate a pathways planning approach into project and strategy development where appropriate

RCS objectives: climate ready assessment

The RCS objectives will significantly contribute to building the adaptive capacity and resilience of the region's communities. With a large component of the catchment under agricultural production, supporting communities to adapt to a changing climate will be an important factor in achieving ecological objectives. A summary of the assessment of RCS objectives for community participation is presented in Table 1.

Table 1: Summary of climate ready assessment of RCS objectives for community participation

RCS Objectives	relevant	revise	Assessment
Objective 2.1: Maintain and enhance community capacity, awareness and involvement in natural resource management within the region	✓		An important action that contributes to adaptive capacity.
Objective 2.2: Facilitate a collaborative approach to NRM	✓		An important action as it has the potential to build social-ecological resilience and contribute to adaptive capacity.
Objective 2.3: Support land managers in meeting their responsibilities as active stewards of the catchment's land, water and biodiversity	✓		An important action that contributes to the adaptive capacity of both social and ecological systems.
Objective 2.4: Support farmers to incorporate environmental outcomes into their farm systems	✓		Essential in maintaining the social-ecological connection but will become increasingly difficult under climate change. Agencies will need to work with communities to identify and prioritise opportunities for joint social and ecological outcomes.

RIVERS AND FLOODPLAINS

Most of the direct impacts of climate change on freshwater systems in the Glenelg Hopkins region are predicted to come from a decline in rainfall leading to a decrease in runoff. Modelling of the Southeast Coast drainage division (including the area covered by the five coastal CMAs in Victoria) found strong agreement across 15 climate models that runoff would decrease[28]. With 1 °C of global warming, average annual rainfall is expected to decline up to 9 % and average annual runoff is expected to decline by 2 to 22 %. For 2 °C of global warming, the reductions in both rainfall and runoff are approximately double[29].

Some generic impacts of climate change on freshwater systems include[30]:

- droughts — which may become more frequent and severe
- dry soil conditions — which may follow decreased rainfall (especially in autumn) combined with increased evaporation
- reduced streamflow
- bushfires, runoff, sediment — increases in temperature, especially during extreme weather and dry catchment conditions, may increase the frequency and intensity of bushfires along with the severity of their impacts on runoff and sediment regimes
- risks to freshwater ecosystems — increased frequency and duration of heatwaves may pose severe risks to freshwater ecosystems
- increased water demand — higher air temperatures, combined with decreased rainfall, may lead to an increase in water demand and exert pressure on the storage reservoirs.

Healthy riparian ecosystems are more resilient to change and more able to adapt to climate change impacts[31]. Improving the current condition of rivers and flood plain areas is the best way of increasing their potential to adapt to a changing climate.

Existing approaches to riparian management such as those undertaken in the Glenelg Hopkins region can be adaptive if undertaken within the climate ready context[32]. Management of non-climate threats through fencing, pest management and flow restoration can reduce the vulnerability of systems and build adaptive capacity. Existing restoration activities, such as riparian revegetation protection, the removal of barriers and the creation of fish ladders, have a critical role to play in reducing the sensitivity of river systems to a changing climate. Under climate change scenarios, the adaptive benefit of ongoing restoration and management can be enhanced if goals remain more open-ended, allowing for a range of future trajectories rather than focusing on meeting specific targets tied to antecedent reference conditions[33]. For example, attempting to restore a river to pre-European settlement states could lead to maladaptation because it does not take into account changing temperature and rainfall patterns.

The region's public land will become increasingly important as they provide refugia, reduce the overall sensitivity of the system and increase adaptive capacity across the landscape. Some important refuge areas for aquatic species have been identified within the Grampians by Parks Victoria, and along the Glenelg River, Wannon River, Crawford River and Mathers Creek in a 2010 study[34]. Protecting existing and potential climate refugia and known resilient systems forms the backbone of biodiversity protection. Landscape-level planning across the Glenelg Hopkins region will be crucial in building the adaptive capacity of systems through improved connectivity via corridors and biolinks. Existing landscape scale projects such as the Glenelg River Restoration Project, Habitat 141 and the Grampians to Pyrenees Biolink provide an opportunity to increase the connectivity of rivers and streams with public land to benefit the ecological resilience of the entire region.

Vulnerability

Vulnerability mapping has been developed using a range of factors for each component, such as exposure, sensitivity and adaptive capacity, as listed in Appendix 2. Figure 6 illustrates the components of exposure, sensitivity and adaptive capacity and their relationship to vulnerability. Vulnerability maps have been developed using RCP8.5 which represents a high-emission scenario for which carbon dioxide concentration reaches about 940 ppm by the end of the twenty-first century[35].

Vulnerability modelling (Figure 8, Figure 9, Figure 10) for rivers shows a significant increase in vulnerability over time. Beyond 2070 most waterways show at least a moderate vulnerability and about a third have a high vulnerability. The main driver responsible for the increase in the vulnerability of rivers is the sensitivity to climate stressors, reduction in March to November rainfall and an increase in November to April maximum temperature. This is particularly evident in the areas north west of Hamilton.

For some areas of the lower Glenelg, vulnerability will remain relatively low from 2050 through to 2090. Much of this area has been fenced and revegetated or protected on public land, improving its condition and therefore its adaptive capacity, indicating that works undertaken on rivers now can decrease their vulnerability to climate change into the future. This highlights the importance of increasing the condition and adaptive capacity of rivers across the region.

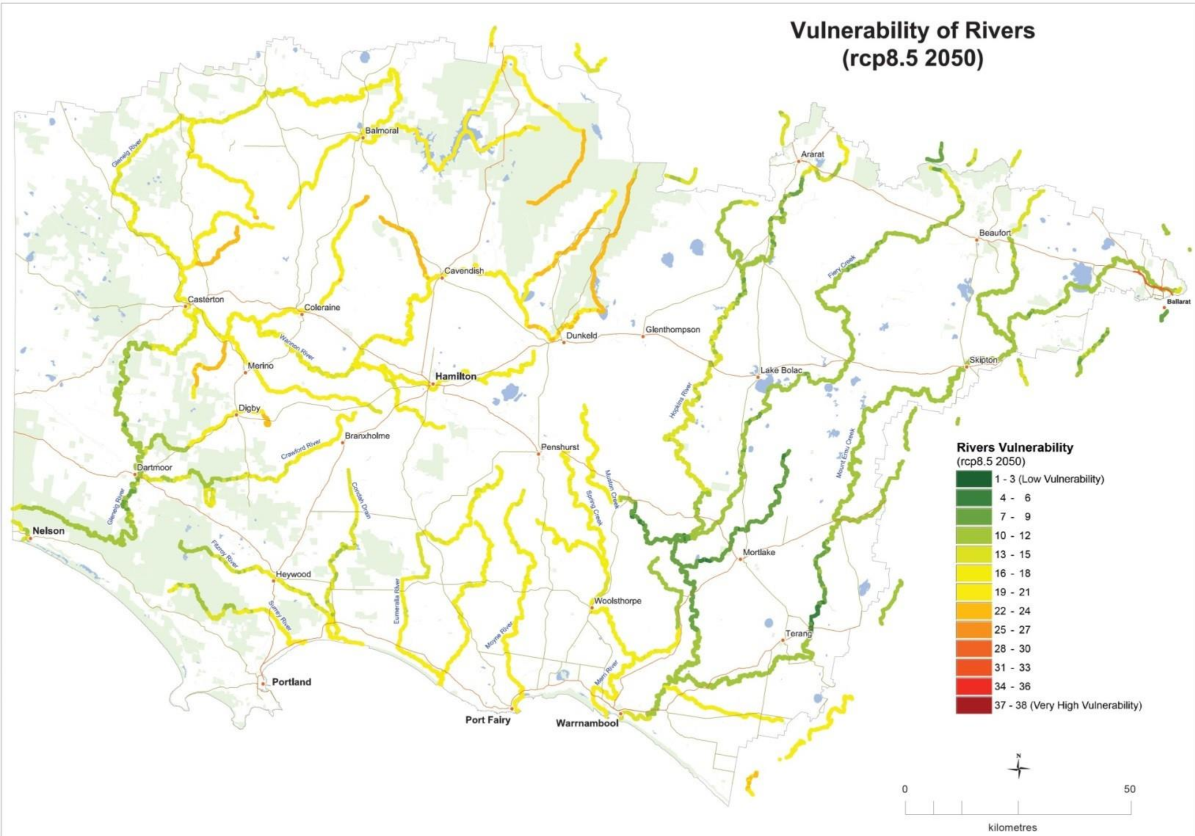


Figure 8: Vulnerability of rivers 2050

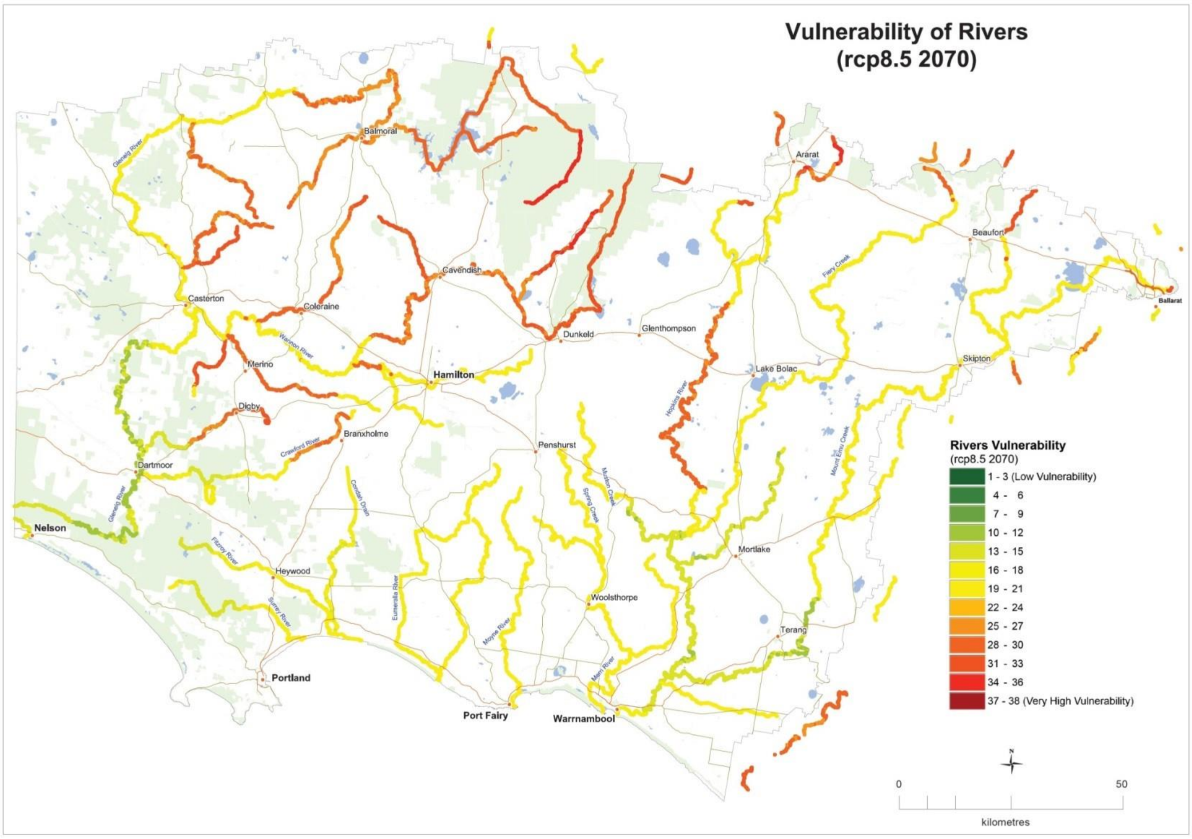


Figure 9: Vulnerability of rivers 2070

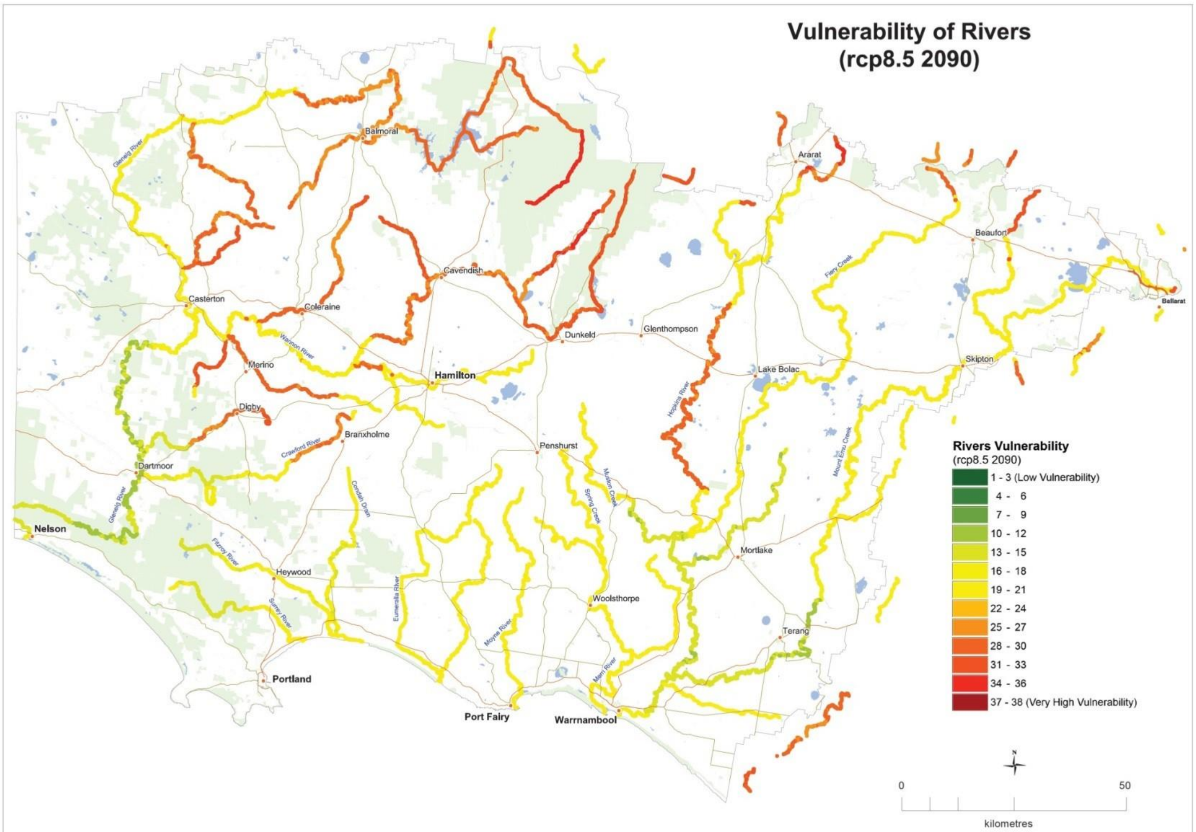


Figure 10: Vulnerability of rivers 2090

Adaptation Planning

The development of an adaptation pathway for rivers and floodplains focused on protecting riparian vegetation and reinstating traditional hydrology of the region. As indicated by the vulnerability mapping, current best practice actions have been successful in building the adaptive capacity of river systems. The CMA will support the protection of high quality riparian vegetation and improve the resilience of identified drought refuge areas. The CMA will also promote the removal of barriers to improve waterway connectivity.

A list of measures was completed. These measures were assessed for their adaptation benefit, potential for maladaptation and relevance over time, and are shown in Table 31 of Appendix 3. The pathway shown in Figure 11 identifies those measures that are considered current best practice or resilience building, the possibility of the asset requiring transformation and the transition between the two phases.

Adaptation Pathway: Rivers and Floodplains

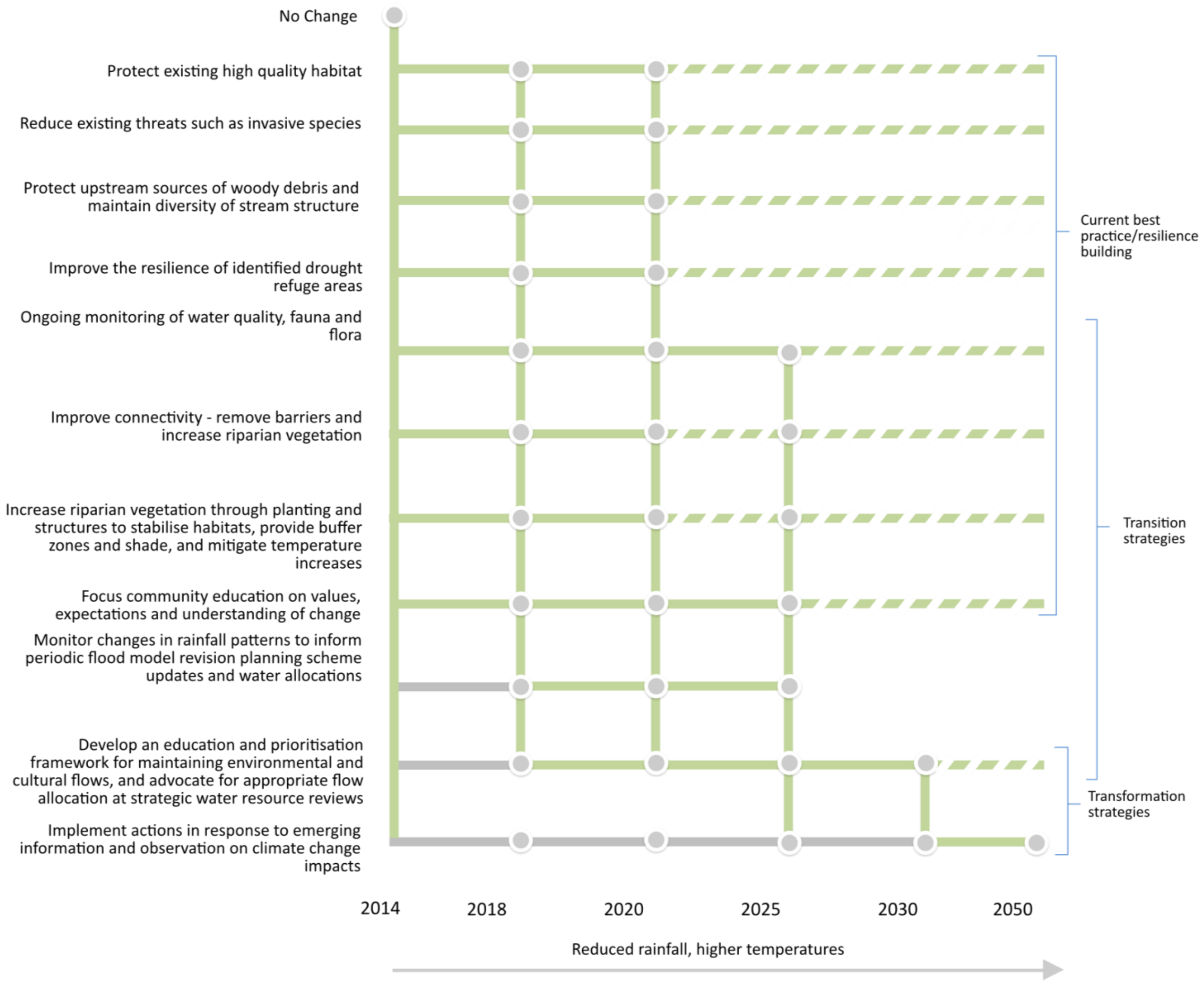


Figure 11: Adaptation pathway for rivers and floodplains

Strategic Direction

Current best practice and resilience-building actions will continue to be relevant to rivers under future climate change scenarios. Glenelg Hopkins CMA will continue to reduce existing threats and protect existing high quality riparian vegetation to help maintain and build the adaptive capacity of river systems. Maintaining high quality riparian habitat is particularly important in protecting species from prolonged periods of heat and drought, as vegetation provides shade, reduces evaporation and mitigates some of the impacts of rising temperatures.

The CMA will support initiatives that maintain and build connectivity throughout and between the region's river systems. Such initiatives will become increasingly important under climate change. This will allow for the movement of species in response to changing climate and extreme events. The CMA will support the protection of refuge areas that will be critical in protecting species from extinction.

Extreme rainfall events also need to be planned for, and keeping natural floodplains open is an approach to mitigating the impacts of flooding. The CMA will collaborate with local and state governments to support the development of waterway and floodplain protection overlays and planning guidelines.

The CMA will continue to support best practice in improving instream and riparian habitat and will work with the community to promote the importance of environmental flows and river health.

Strategic Initiatives

- Protect existing high value waterways and waterway dependent species and communities through managing existing threats
- Identify key indicator variables and resilience thresholds for climate change impacts on waterways, monitor change in waterway environments and revise management objectives in the Regional Waterway Strategy
- Monitor land use change and its relation to runoff and catchment hydrology
- Periodically review rainfall and river flow changes to inform water allocation and flood planning
- Identify drought refuge areas and prepare plans for their protection
- Encourage community participation in waterway health monitoring to facilitate improved information quality and involvement in the revision of management objectives and priorities
- Contribute to the periodic review of water resource availability and ensure reallocation protects waterway health
- Support the development of waterway and floodplain protection overlays and planning guidelines

RCS objectives: climate ready assessment

The RCS objectives for rivers and floodplains generally remain relevant and become increasingly important under climate change. A summary of the assessment of RCS objectives for rivers and floodplains is presented in

Table 2.

Table 2: Summary of climate ready assessment of RCS objectives for rivers and floodplains

RCS Objective	relevant	revise	Assessment	Revised Objective
Objective 3.1: Waterways classified as good or excellent in the Index of Stream Condition (ISC3) will remain as such in 2033	✔		Keeping rivers in good or excellent condition will become increasingly difficult under climate change. Consideration of the feasibility of this target will be required at each strategy review	
Objective 3.2: The condition of specified waterways currently classed as poor to moderate in the Index of Stream Condition (ISC3) is improved by 2033	✔	✔	Improving condition will become increasingly difficult The objective remains relevant under the timeframe of the current RCS, although will require revision for development of the next RCS	Prevent further decline of specified waterways currently classed as poor to moderate in the Index of Stream Condition (ISC3)
Objective 3.3: Improve river health in relation to riparian extent, connectivity, hydrological regime and water quality	✔	✔	Will contribute greatly to increased adaptive capacity of river systems under a changing climate The objective remains relevant under the timeframe of the current RCS, although will require revision for the next RCS iteration	Maintain river health in relation to riparian extent, connectivity, hydrological regime and water quality
Objective 3.4: Increase provision of reliable flood information for settlements	✔		Increasingly important under climate change as risk of flood increases	Increase provision of reliable flood information for settlements with climate change considerations
Objective 3.5: Improve river and floodplain management	✔		Increasingly important under changing climate	

WETLANDS

The wetlands of the Glenelg Hopkins region are a crucial component of the natural environment and contribute significantly to the ecological, social and agricultural health of the region. The catchment includes more than 5,400 wetlands, covering 73,000 hectares (ha) or 3% of the region's area. This represents 14% of Victoria's total area of wetlands and 44% of the state's total number of wetlands[36]. Distribution of wetlands and priority wetland areas in the region are indicated in Figure 12.

Vin Gannon

Wetlands of the Glenelg Hopkins region have been acknowledged as key areas for conservation under a number of international agreements. Lake Bookaar, near Camperdown, is recognised under the Ramsar agreement as a wetland of international importance[37] and several other wetlands fall within the flyways of bird species recognised under international treaties (Japan-Australia Migratory Bird Agreement, China-Australia Migratory Bird Agreement and Republic of Korea-Australia Migratory Bird Agreement). In addition, there are four Important Bird and Biodiversity Areas (IBAs) and 16 wetlands that are listed in the Directory of Important Wetlands of Australia (DIWA).

Many wetlands in the region have been lost or degraded to various extents. Since European settlement, many wetlands have been drained, reducing their extent and connectivity[38]. They have also been affected by grazing, cropping and the establishment of tree plantations.

The region's wetlands are integral to healthy functioning ecosystems in the landscape, regulating water quality and contributing to biodiversity. They receive runoff, absorb and filter floodwaters, replenish groundwater reserves and act as direct surface water supplies[39]. Wetlands play a significant role in storing sedimentary organic carbon, and account for a substantial portion of carbon stocks with the Glenelg Hopkins region[40].

The region's wetlands range from large and permanent freshwater lakes to small and ephemeral (non-permanent) freshwater meadows. Each wetland type has unique plant diversity and provides habitat for a range of birds, frogs, reptiles, fish and invertebrate species.

Wetlands are among the ecosystems most vulnerable to climate change. The most evident impact on wetlands within the Glenelg Hopkins region will come from changes to rainfall and increased temperatures. Decreased rainfall will impact hydrological regimes and extreme weather events (heatwaves, droughts, storms and floods) will become more frequent and intense.

In spite of their vulnerability it is recognised that many wetlands are highly resilient by nature. For example, seasonal herbaceous wetlands (SHW) are adapted to drying out for long periods of time and although dry periods are increasing and becoming more frequent, they have still shown an ability to recover quickly when wetting occurs. However, the recovery and adaptive capacity of the region's wetlands will be related to the connectivity of wetlands and wetland complexes.

Since the release of the RCS, Seasonal Herbaceous Wetlands (Freshwater) of the Temperate Lowland Plains have been listed as critically endangered under the *Environmental Protection and Biodiversity*

Conservation Act *2012* (Cwlth). Seasonal herbaceous wetlands are isolated freshwater wetlands that are usually seasonally inundated through rainfall and then dry out, so surface water is not permanently present. Because they are not always visible and are reliant on rainfall, they are particularly prone to degradation from land use change and vulnerable to reductions in rainfall under climate change.

The region's low-lying coastal wetlands and shallow wetlands that rely on direct rainfall are most likely to be affected by climate change. A future hotter and drier climate in the Glenelg Hopkins region will reduce many wetlands in size, convert some wetlands to dry land or shift them from one wetland type to another. Climate change and rising sea levels will likely lead to a significant loss and degradation of wetlands and associated biodiversity[41].

All wetlands types within Glenelg Hopkins region currently face a range of threats that will be exacerbated and augmented by climate change. The two wetland types that will be most vulnerable to climate change are the coastal and seasonal herbaceous wetlands.

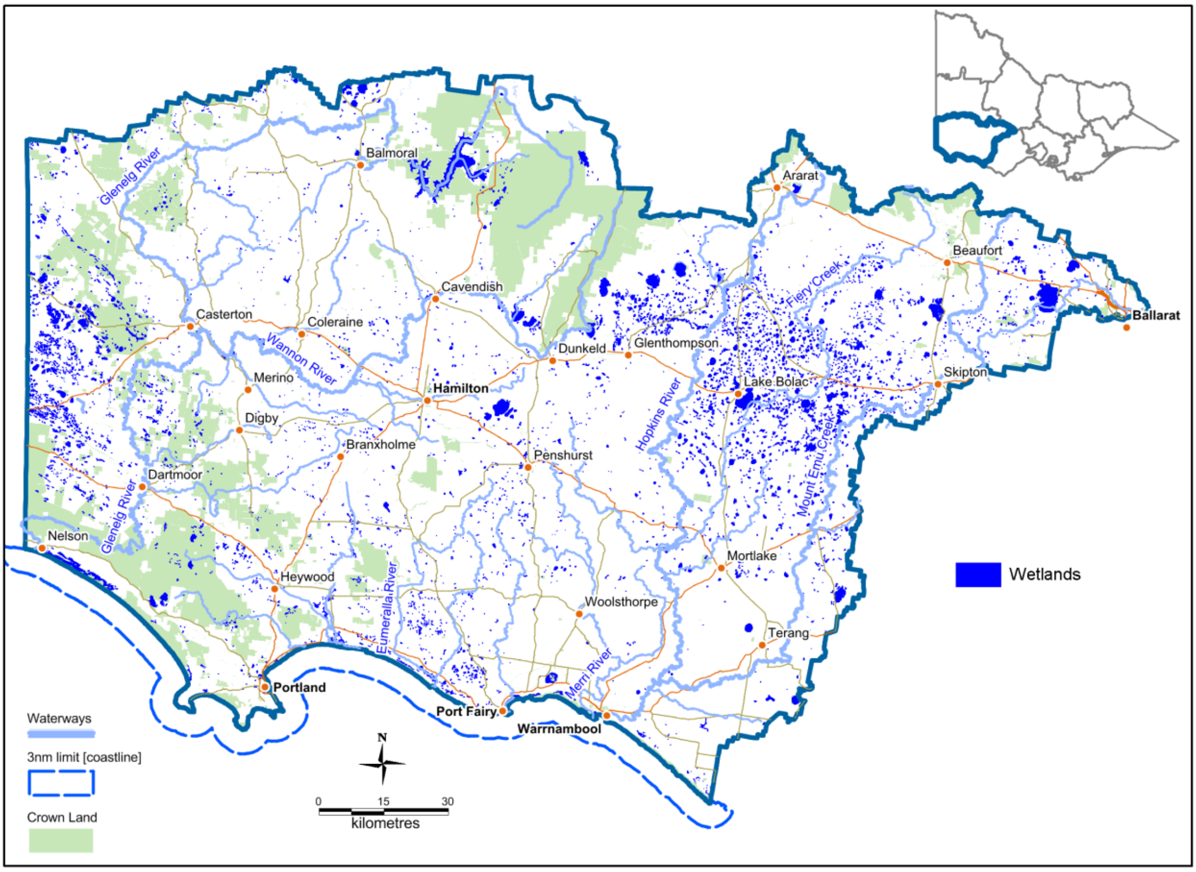


Figure 12: Wetlands within the Glenelg Hopkins Region

Vulnerability

Vulnerability mapping has been developed for the wetland asset using a range of factors for each component, including exposure, sensitivity and adaptive capacity, as listed in Appendix 2. The components of exposure, sensitivity and adaptive capacity and their relationship to vulnerability are illustrated in Figure 6. The maps have been developed using RCP8.5 which represents a high-emission scenario, for which carbon dioxide concentration reaches about 940 ppm by the end of the twenty-first century[42].

The vulnerability mapping for wetlands shows a significant increase in vulnerability over time (Figure 13, Figure 14, Figure 15). The wetlands in the west of the region and along the coast are the first to become highly vulnerable, some as early as 2050. This is a result of their sensitivity to the reduction in rainfall.

The majority of wetlands in the region are considered to become highly vulnerable by 2070, with only the larger wetlands remaining in the mid range. In addition, coastal wetlands will be vulnerable to sea level rise and the risk of erosion and inundation due to storm surge, which are likely to occur before 2050.

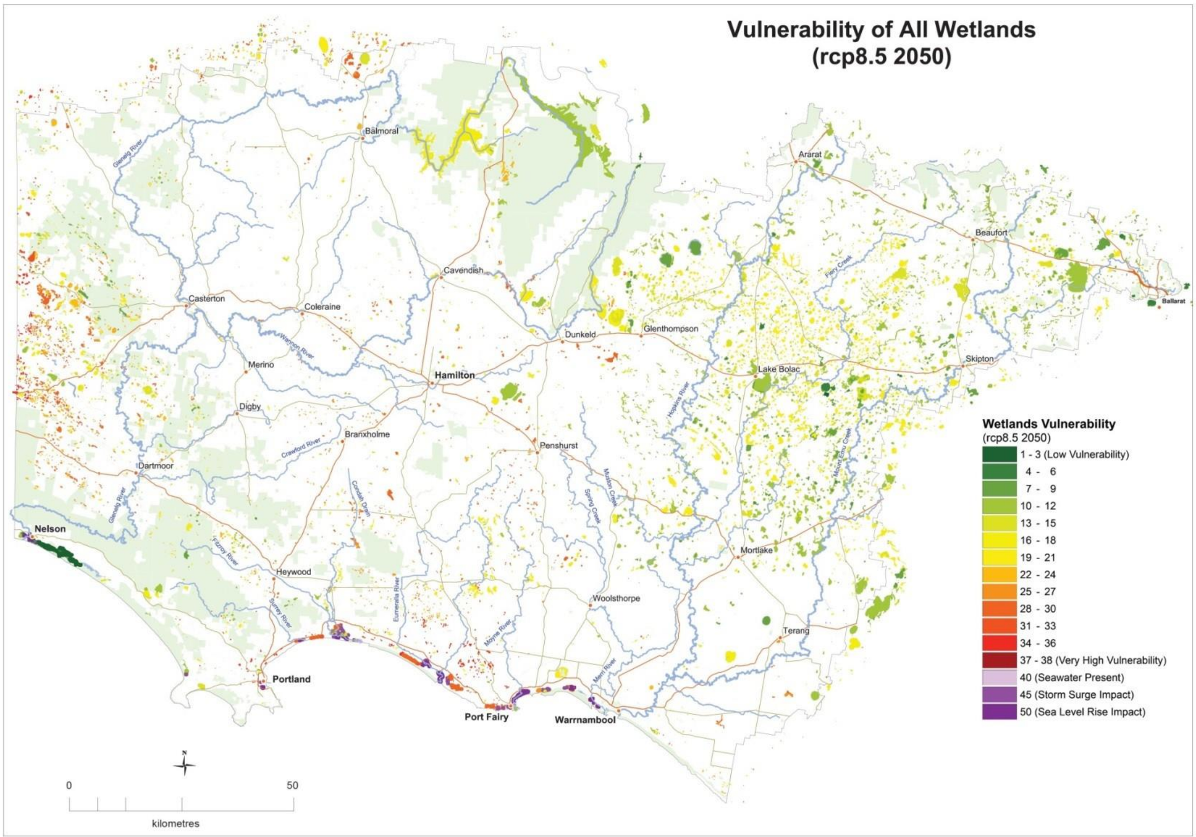


Figure 13: Vulnerability of wetlands 2050

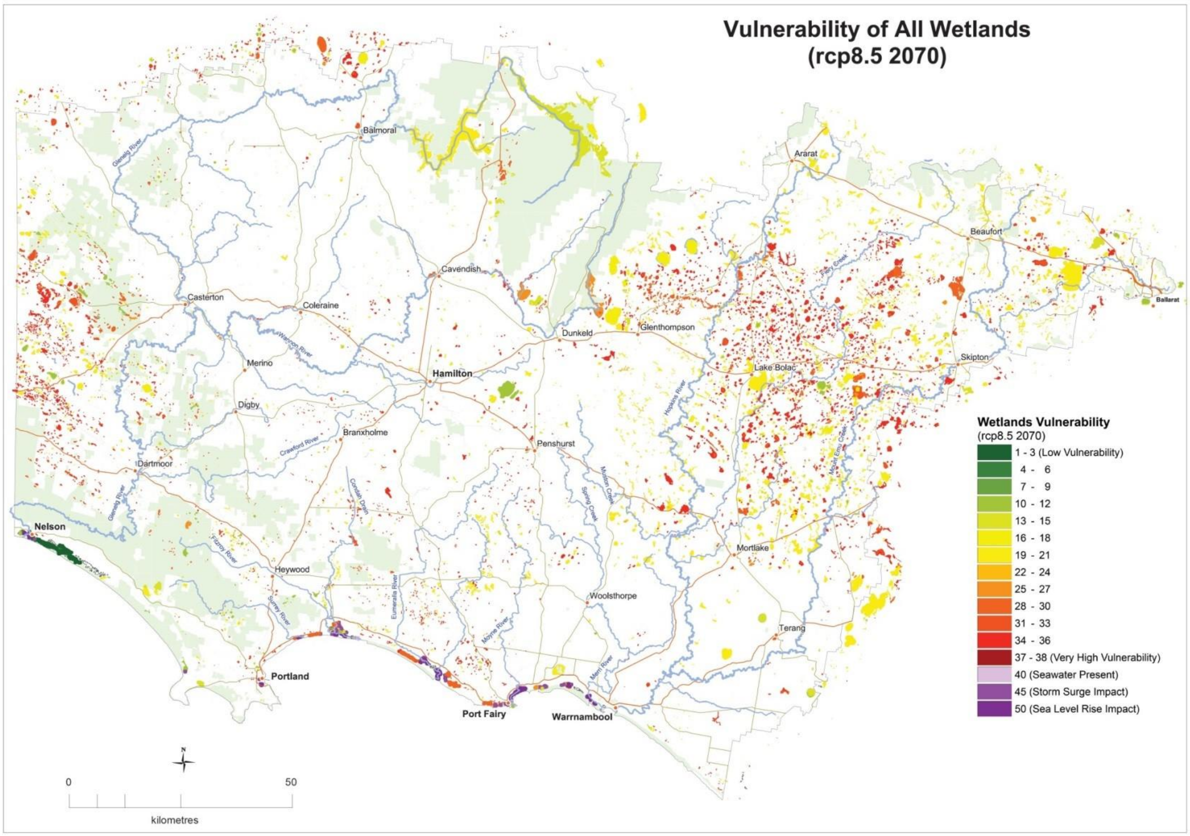


Figure 14: Vulnerability of wetlands 2070

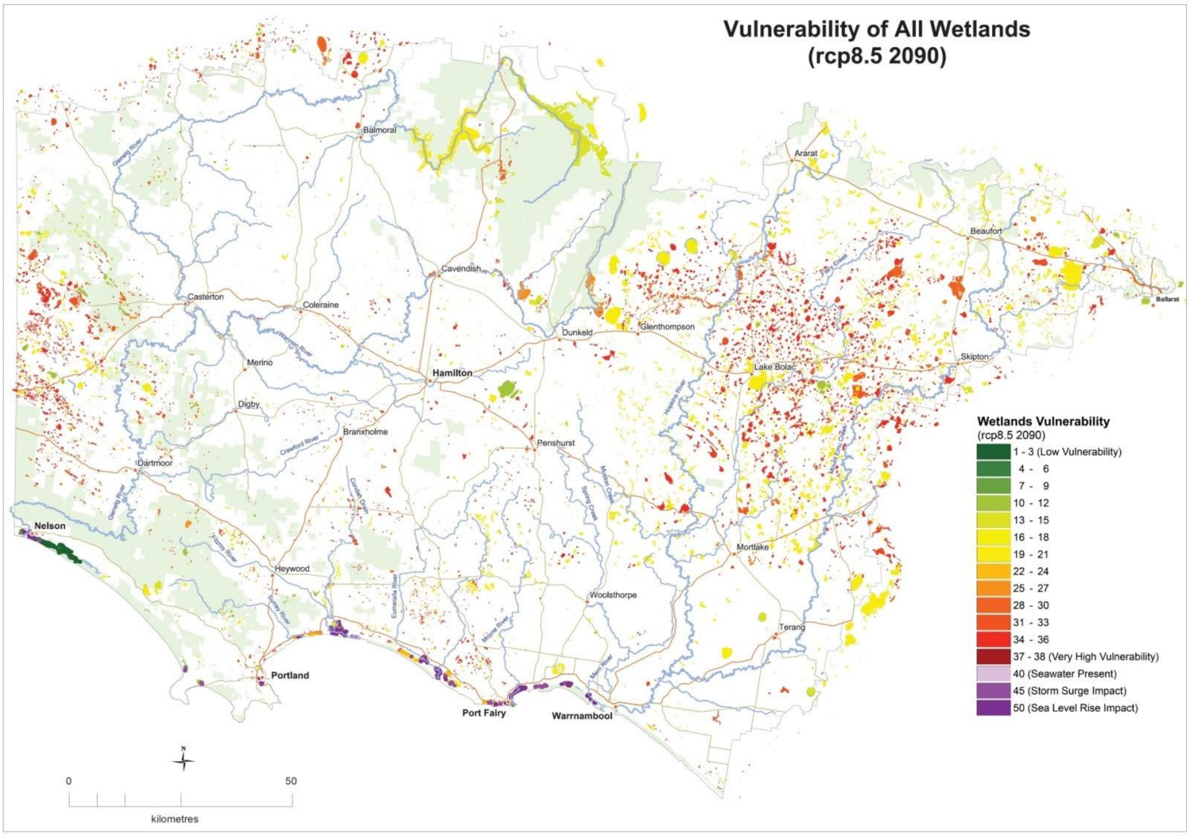


Figure 15: Vulnerability of wetlands 2090

Adaptation Planning

The adaptation pathway for wetlands has a focus on the reinstatement of traditional hydrological regimes in addition to addressing existing threats. As this is already considered best practice in restoring wetland systems and communities, the long-term goal for protecting and improving the adaptive capacity of wetlands is considered to be a change towards actively managing wetlands as part of productive agricultural systems. It is also recognised that current knowledge of the extent and condition of wetlands is lacking and that mapping and long-term monitoring programs will be an important component of adaptive wetland management under a changing climate.

A list of measures was completed and the measures assessed for their adaptation benefit, potential for maladaptation and relevance over time. These are shown in Table 32 of Appendix 3. The pathway shown in Figure 16 works through those measures that are considered current best practice or resilience building, the possibility of the asset requiring transformation and the transition between the two phases.

Adaptation Pathway: Wetlands

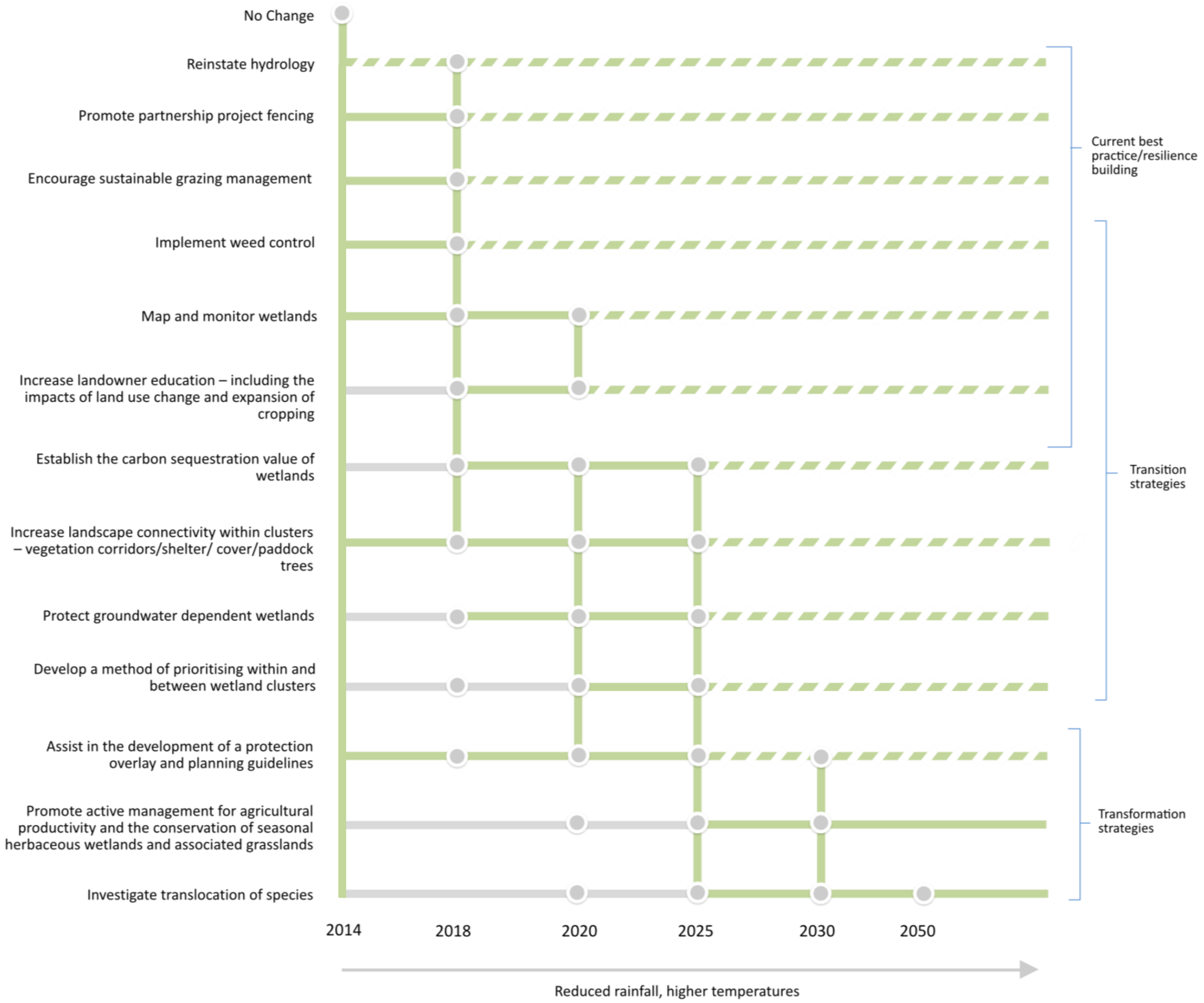


Figure 16: Adaptation pathway for wetlands

Strategic Direction

The major threat to seasonal herbaceous wetlands under climate change is the potential for their degradation during increasingly long dry periods and the increasing threat from land use change in the region. With an increasingly drier climate there has been a shift from grazing to cropping within the Glenelg Hopkins region, and this trend is likely to continue.

Currently grazed wetlands can continue to be grazed in a way that will help maintain their biodiversity and function; however, cropping can result in their complete destruction and loss from the landscape over time. Of particular risk is the potential for raised-bed cropping to become more prevalent in the region, which would significantly change the hydrology of the landscape. Although many wetlands are currently persisting within the region, longer dry periods and land use change could mean the complete loss of some wetlands in the long term, unless their location, structure and function can be better identified, understood and protected. Glenelg Hopkins CMA will collaborate with local and state governments to progress the development of appropriate overlays in planning schemes and planning guidelines to increase protection and raise the value of wetlands in the eyes of the community and landholders.

In this particular pathway map the resilience-building actions are those that are currently being implemented and considered best practice. The transitional actions focus on activities required to increase the knowledge of seasonal herbaceous wetlands. This will facilitate the move to future management of agricultural landscapes for the mutual benefit of ecological function and agricultural productivity. Glenelg Hopkins CMA will collaborate with partners to expand current knowledge of the region’s wetlands.

The final transformational activity relates to the possibility that species shifts and local extinctions may require the translocation of northern species into remaining seasonal herbaceous wetlands. The species diversity of seasonal herbaceous wetlands is significantly different in the north of the state and, if natural connectivity and dispersal prove to be insufficient, translocation may be required to maintain the diversity and function of wetlands, even if the suite of species must change.

It has also been recently recognised that wetland systems play an important role in climate change mitigation through the capture of organic carbon. Carbon captured in wetlands and coastal vegetation systems is referred to as blue carbon. A Deakin University report commissioned by Glenelg Hopkins CMA has concluded that the restoration of wetlands and natural hydrology would result in significant carbon sequestration as well as having additional social, ecological and economic benefits[43]. The CMA will prioritise the protection and enhancement of wetlands across the region and commit to further investigation of wetland carbon sequestration potential.

Glenelg Hopkins CMA is committed to improving the condition of wetlands and will continue to support projects and programs that help to improve biodiversity and function according to best practice. Raising the social value of wetlands and their importance will be crucial to future planning for their protection and opportunities to engage with communities and to work together to build the resilience of wetland systems will be actively pursued.

Strategic Initiatives

- Increase wetland protection and restoration based on their value to both biodiversity and carbon sequestration
- Further investigate the carbon storage and sequestration potential of wetlands
- Contribute to the development of a carbon sequestration or emission abatement methodology for wetland protection and restoration to provide additional financial incentives for landholder management
- Monitor rainfall and wetland hydrology under climate change and establish thresholds for resilience
- Monitor land use change and its impacts on wetland hydrology
- Pursue the development of a wetland protection overlay and planning guidelines

RCS objectives: climate ready assessment

The RCS objectives for wetlands remain relevant and become increasingly important under climate change. A summary of the assessment of RCS objectives for wetlands is presented in Table 3.

Table 3: Summary of climate ready assessment of RCS objectives for wetlands

RCS Objective	relevant	revise	Assessment	Revised Objective
Objective 4.1: By 2033, improve the condition of wetlands, and maintain the diversity of wetland types (using IWC1 assessment for comparison)	✓		Improving the condition and diversity of wetlands will be essential in building their adaptive capacity and maintaining function as composition and hydrology change	n/a
Additional objective				Improve the resilience of wetlands to climate related change
Additional objective				Monitor the impact of land use change on wetland hydrology
Additional objective				Improve understanding of the contribution of wetlands to carbon sequestration
Additional objective				Investigate the restoration potential of wetlands across the region

COASTS AND ESTUARIES

Coasts are the interface between marine and terrestrial environments. They include beaches, cliffs, intertidal zones, coastal wetlands, marshes, mangroves, lagoons, coastal floodplain forests and the estuarine portions of waterways.

Estuaries within the Glenelg Hopkins region are experiencing sea surface temperatures increasing at a rate of approximately four times the global average, which has potentially significant consequences for marine and estuarine species[44]. Temperate locations such as the Glenelg Hopkins region and cool water species are the most likely to be negatively impacted by increasing water temperature. Increased temperatures may exceed the optimal temperature range of certain species, particularly those species with limited thermal ranges.

The coastline of the Glenelg Hopkins region is subject to coastal erosion, sea level rise and flooding. With a changing climate, these impacts will be exacerbated with increases in wind speed, storm intensity and frequency, as well as changes in rainfall intensity and frequency[45].

A 2005 CSIRO study[46] indicated that mean sea level rise will provide the largest contribution to future flood risk. Under the worst-case, wind speed scenario, storm tide height would increase by up to 5 cm in 2030 and 20 cm in 2070. The 2030 and 2070 high-wind scenarios produce increases in storm tide height that are about 19% of the respective mean sea level rises.

The Victorian Government's coastal policy recommends to 'plan for sea level rise of not less than 0.8 metres by 2100, and allow for the combined effects of tides, storm surges, coastal processes and local conditions, such as topography and geology when assessing risks and impacts associated with climate change'[47]. It is noted that as more scientific data becomes available, planning for a sea level rise of not less than 0.9 metres by 2100 is a more conservative option and maybe desirable[48].

Current Intergovernmental Panel on Climate Change (IPCC) predictions indicate that if emissions continue to track at the top of IPCC scenarios, global average sea level could rise by nearly 1 m by 2100 (0.52–0.98 m from a 1986–2005 baseline)[49]. If emissions track along the lowest scenario, then global mean sea level, (GMSL) could rise by 0.28-0.60 m by 2100 (from a 1986–2005 baseline). The IPCC also states that 'with regional variations and local factors, the local sea level rise can be higher than that projected for the GMSL'[50].

Climate change will see increases in wind speed, storm intensity and frequency and changes in rainfall frequency in the Glenelg Hopkins region[51]. These climate variables will not produce new coastal hazards, but are likely to increase the extent or frequency of existing hazards[52]. The Glenelg Hopkins coastline is subject to coastal inundation, coastal erosion/recession, sea level rise and flooding which will be exacerbated because of a number of factors, including changes in:

- mean sea level
- storm climates (storm surges, storm tides and atmospheric changes)
- tidal ranges
- wave climates
- rainfall.

The region's low-lying coastal wetlands and shallow wetlands rely on direct rainfall and are affected by saltwater intrusion from the sea. Climate change will impact on these ecosystems as a result of increased drought frequency and intensity, decreases in freshwater inputs, rising sea levels and increases in coastal storm surges. These conditions may also change the character of coastal wetlands through a reduction in size, conversion to dryland or a shift from one wetland type to another (e.g. brackish to saline)[53]. The retention of coastal wetlands will require planning approaches which allow for the landward movement of wetland communities in order to avert significant loss and degradation to coastal wetlands and associated biodiversity within the Glenelg Hopkins region.

The Victorian Government has provided a package of tools to support decision making, including inundation maps, planning notes and guidelines[54]. Some of the modelling and information on inundation and coastal erosion contained has been based on the Bruun rule[55]. The Bruun rule may lack the complexity required to predict shoreline behaviour under a rising sea level[56]. The linkages between sea level rise and shoreline response are extremely complex and require a tool that will adequately address this complexity. An adaptive and flexible approach is required for planning in order to address the multiple uncertainties relating to the exact nature of coastal erosion in response to sea level rise and storm surge events.

Coastal Wetlands

The Glenelg Hopkins coastal wetlands are not only at risk from hydrological and climatic changes but are also subject to sea level rise and storm surge events. Coastal wetlands in the region's urban and agricultural areas are also subject to coastal squeeze as their ability to migrate inland is restricted by surrounding land uses.

Coasts and coastal wetlands are at the interface between marine and terrestrial environments. During periods of sea level rise, coastal wetlands can persist only when they accrete soil vertically at a rate at least equal to water level rise[57]. Because freshwater runoff carries sediments that increase accretion, there is concern that reduced freshwater runoff decreases the supply of sediments. Saltwater intrusion as a result of rising sea levels, increases in coastal storm surges, decreases in freshwater inputs, and increased drought frequency and intensity, are very likely to expand the areas of salinisation of coastal freshwater aquifers and coastal wetlands[58]. The region's coastal wetlands may disappear as a result of predicted increases in shoreline erosion, made worse by dieback of shoreline plants caused by increased salinity[59].

Vulnerability

Vulnerability mapping has been developed for the coast and estuaries asset using a range of factors for each component, including exposure, sensitivity and adaptive capacity, as listed in Appendix 2. The components of exposure, sensitivity and adaptive capacity and their relationship to vulnerability are illustrated in Figure 6. The maps have been developed using RCP8.5 which represents a high-emission scenario, for which carbon dioxide concentration reaches about 940 ppm by the end of the twenty-first century[60].

The vulnerability of estuaries and coastal areas to climate change (see Figure 17, Figure 18, Figure 19) is much higher and manifests earlier than for other assets in the region, despite having a very high adaptive capacity. The main drivers responsible for this vulnerability are the sensitivity to reduction in rainfall and exposure to sea level rise. The majority of the asset is susceptible to storm surge and sea level rise. Long Swamp located in the far south west of the catchment maintains low vulnerability out to 2090. This is due to its high adaptive capacity and low sensitivity to reduced rainfall.

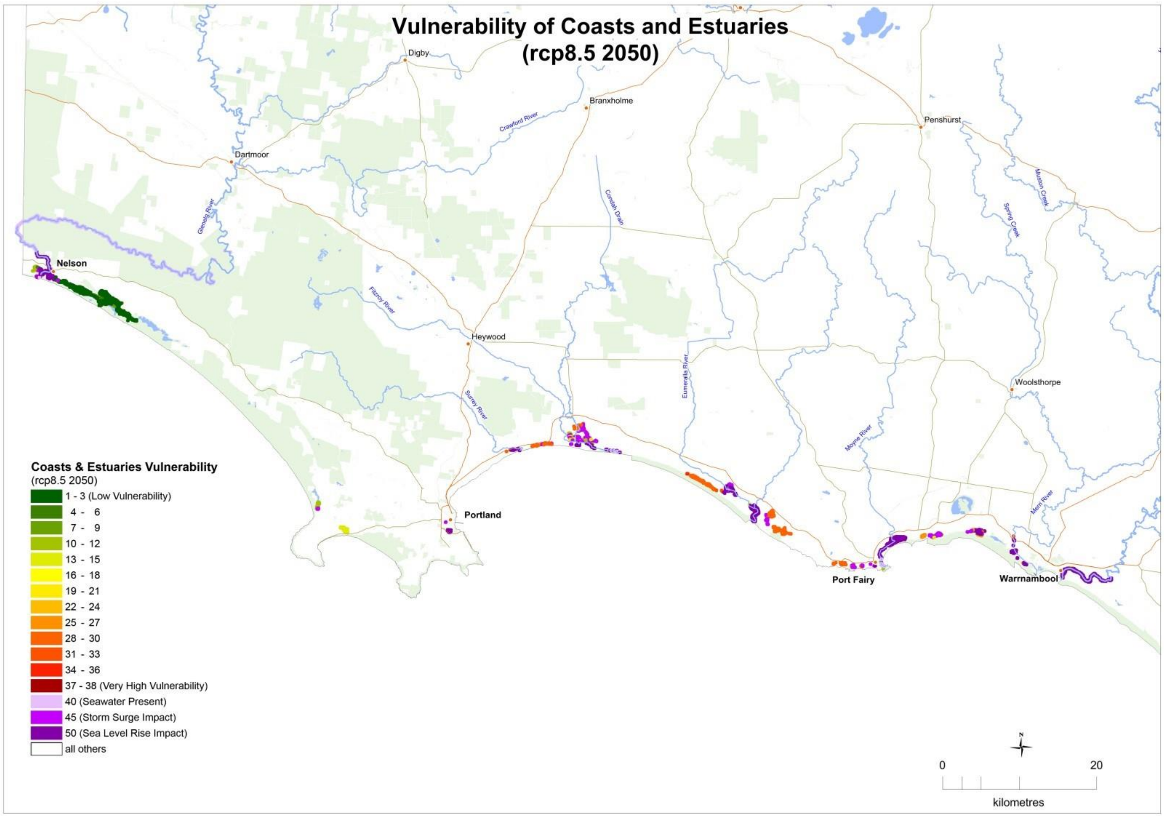


Figure 17: Vulnerability of coasts and estuaries 2050

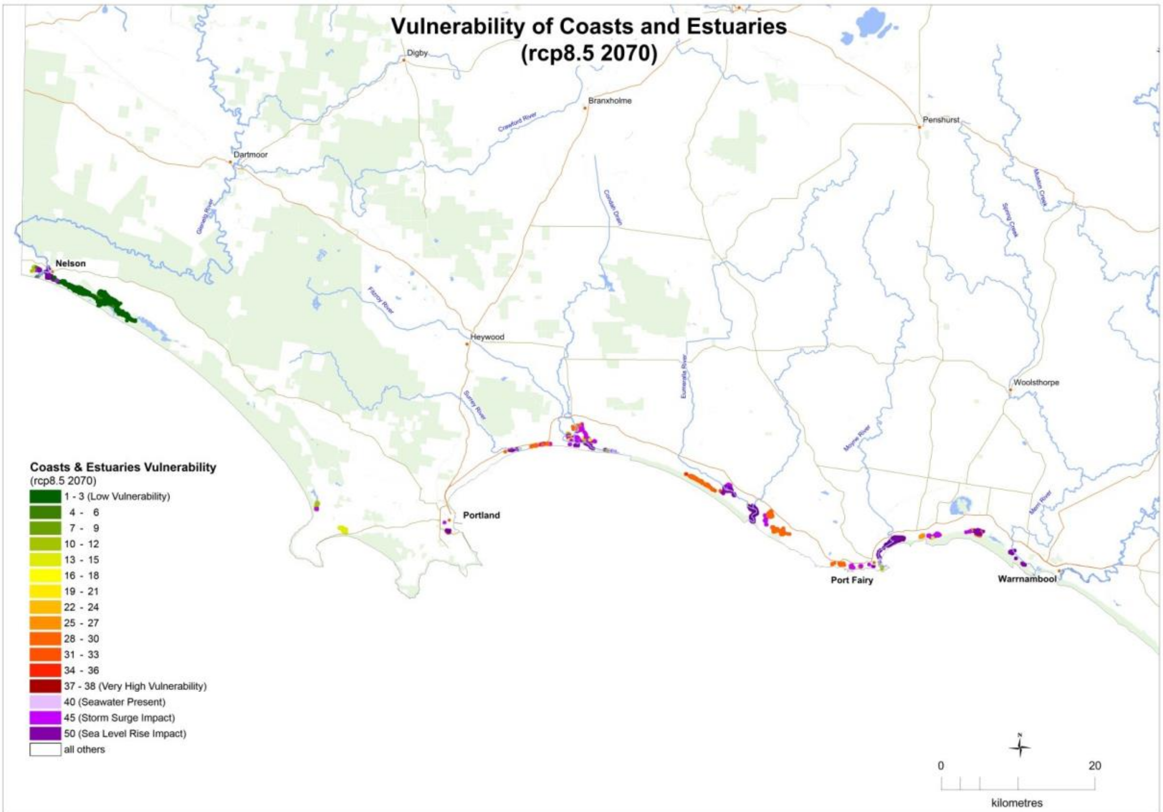


Figure 18: Vulnerability of coasts and estuaries 2070

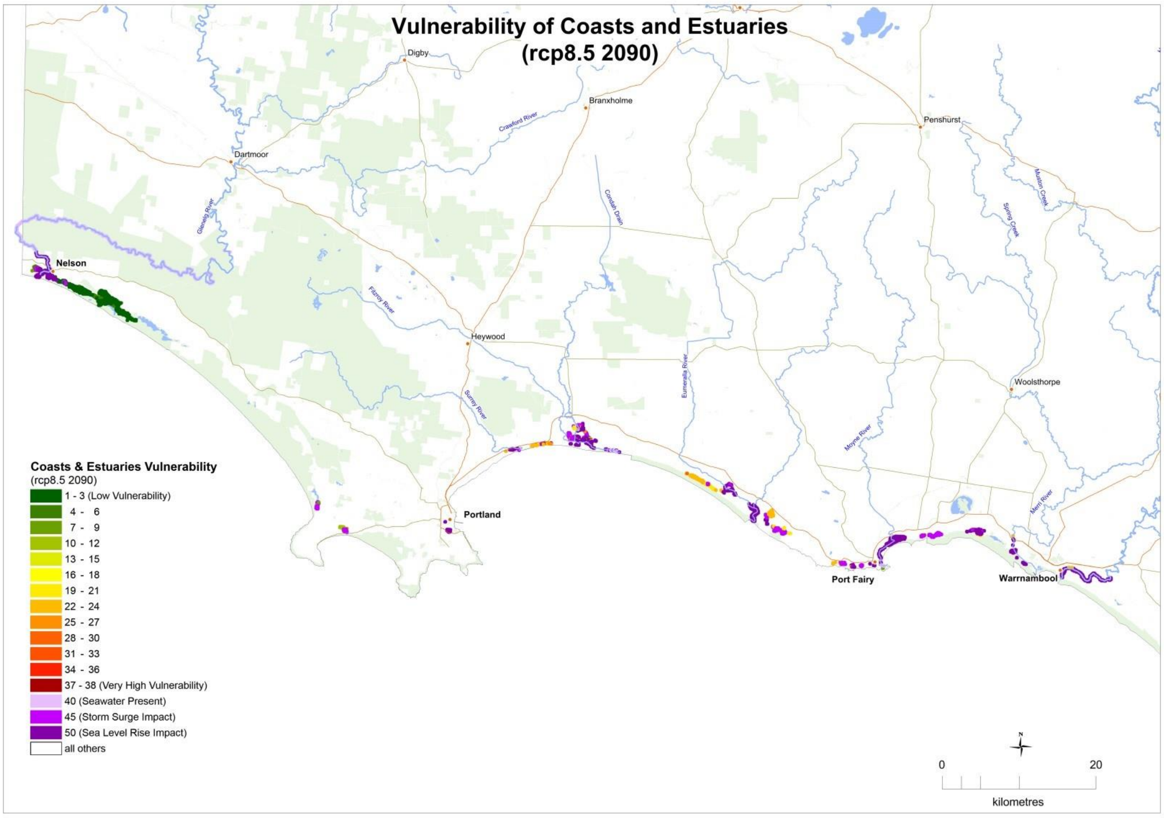


Figure 19: Vulnerability of coasts and estuaries 2090

Adaptation Planning

The development of the coasts and estuaries adaptation pathway shown in Figure 20 focused on identifying current best practice and highlighting the key issues for coastal and estuarine systems under a changing climate. Experts identified that a fundamental component to allowing for coastal adaptation will be the development of planning tools which are flexible and allow for innovation in accommodating change, and new research and technology. This will require significant investment in research as well as community engagement and consultation with local government to achieve changes to planning schemes.

A list of measures was completed. These measures were assessed for their adaptation benefit, potential for maladaptation and relevance over time and are shown in Table 33 of Appendix 3. The pathway shown in Figure 20 identifies those measures that are considered current best practice or resilience building, the possibility of the asset requiring transformation and the transition between the two phases.

Adaptation Pathway: Coasts and Estuaries

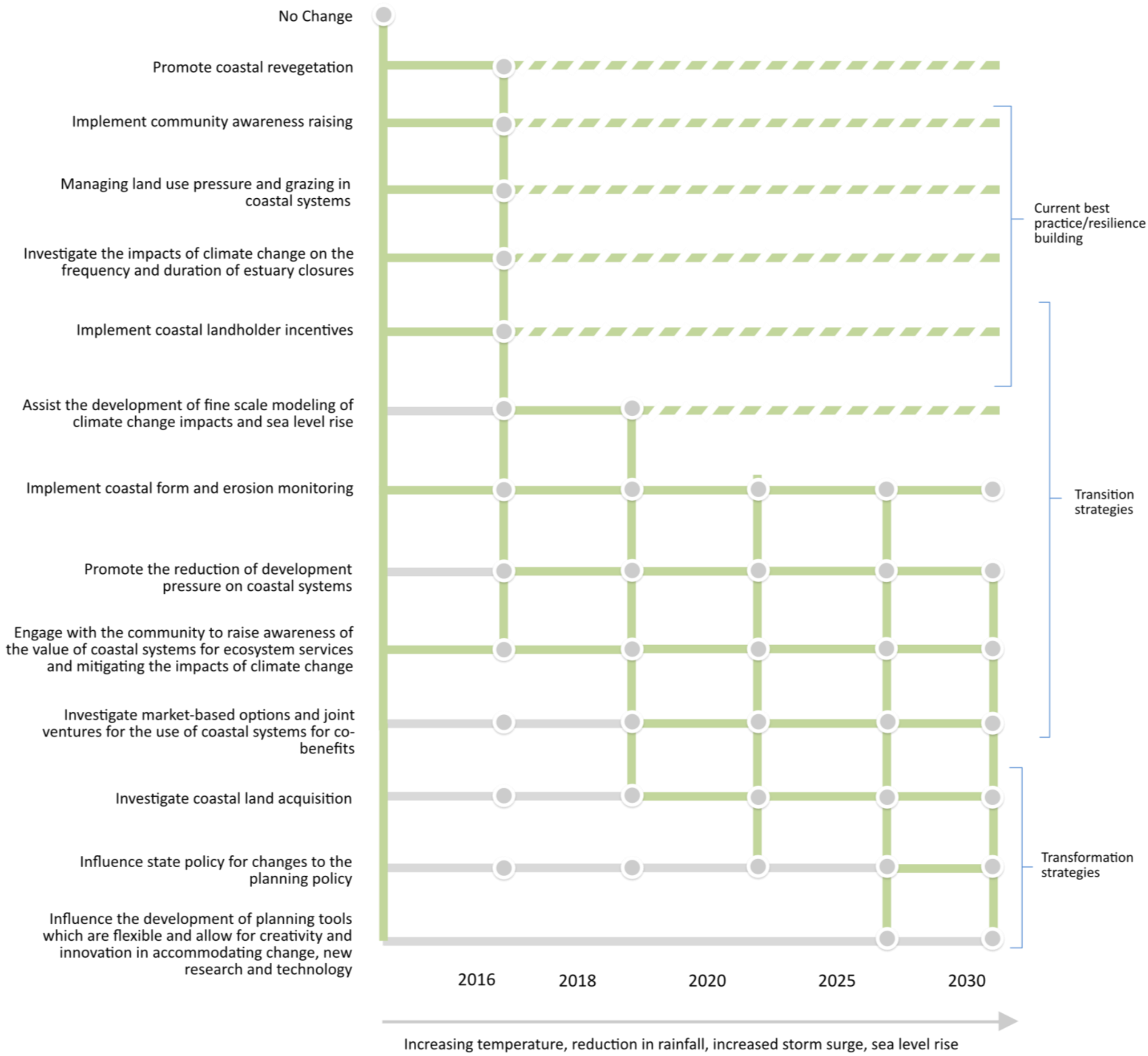


Figure 20: Adaptation pathway for coasts and estuaries

Strategic Direction

During the development of the adaptation pathway a mismatch was identified between planning for rivers, planning for estuaries and planning for coasts within the Glenelg Hopkins region and throughout Victoria. These interconnected systems need uniform planning controls to allow for appropriate management, particularly under a changing climate and in response to sea level rise and storm surge. The CMA will collaborate to support the integration and streamlining of planning for rivers, estuaries and coasts.

Current coastal management focuses on building the resilience of coastal systems and raising awareness regarding the value of coastal systems. However work to date has not succeeded in protecting coastal systems from inappropriate land use and development, and will be insufficient to protect coastal systems from climate change, including sea level rise and storm surge[61]. As sea level rises and storm surge exacerbates coastal erosion, the coastal zone will be squeezed between the rising ocean and infrastructure development. To protect the social and ecological values of the coast for public benefit, the extent of coastal public land will need to increase landward, allowing room for coastal systems to move. The use of long-term management agreements and covenants may be a valuable first step, yet the acquisition of additional coastal public land may be required to maintain ecosystem services. Glenelg Hopkins CMA will support the establishment of covenants to protect coastal assets and enable coastal migration. Although land swaps are a challenging concept they may become a viable option in the future.

There is a need for research and modelling on the finer scale impacts of sea level rise and storm surge, particularly on the erosion of dune systems and the role of vegetation in dune stabilisation. Glenelg Hopkins CMA will prioritise support for the development of fine scale modelling which will assist in planning for adaptation and prioritisation.

Market-based instruments and offsets may be used to identify the value of coastal land for conservation. The CMA will support implementation of coastal land tenders and stewardships to protect it from inappropriate land use and development. It is important to accept the inevitable changes associated with sea level rise and explore innovative solutions to maintaining ecological function of the coast.

Protecting and improving coastal habitats is also important in regard to climate change mitigation and carbon sequestration as coastal habitats have been found to store carbon at almost 40 times the rate of terrestrial vegetation[62]. The carbon stored in coastal and wetland habitats is known as 'blue carbon'. It is crucial that vegetated coastal habitats are protected to prevent the release of this carbon into the atmosphere. The enhancement and creation of coastal habitats could contribute significantly to the mitigation of carbon emissions[63].

Glenelg Hopkins CMA will continue to implement best practice actions for the protection and enhancement of coastal systems. Programs that support long-term monitoring and research regarding the impacts of sea level rise and carbon sequestration potential will be supported and opportunities for development of innovative solutions for adaptation will be encouraged.

Strategic Initiatives

- Increase coastal and estuarine protection and restoration based on their value to both biodiversity and carbon sequestration
- Further investigate the carbon storage and sequestration potential of coastal systems and the best means of long-term protection
- Support research on the fate of carbon in saltmarsh habitat subject to erosion
- Support community monitoring of coastal form and change over time
- Identify and monitor key indicators of coastal climate change impacts
- Periodically review objectives in the Regional Waterway Strategy and estuary management plans to incorporate climate change factors
- Investigate the impact of climate change on the frequency and duration of estuary closures
- Monitor land use change and its impacts on coastal and estuarine systems
- Monitor changes in rainfall patterns and sea level rise to inform the revision of flood models, and integrate information into planning schemes
- Support the development of fine scale modelling of climate change impacts and sea level rise on coastal and estuarine systems

RCS objectives: climate ready assessment

The RCS objective for coasts and estuaries does not meet the climate ready criteria as explained in

Table 4. Adaptive capacity will be built through managing current threats to condition, although the maintenance of condition may not be possible. Climate change threats such as sea level rise and storm surge will have significant impacts on coastal condition.

Table 4: Summary of climate ready assessment of RCS objectives for coasts

RCS Objective	relevant	revise	Assessment	Revised Objective
Objective 6.1: By 2033 maintain the condition of the coast and manage specific threats to improve condition where appropriate		✓	The condition of the coast may not be able to be maintained in the face of climate change and sea level rise Managing threats other than climate change is essential in maintaining and building adaptive capacity Allowing for landward migration of communities will be a significant challenge	Manage specific threats to coastal systems and improve condition where appropriate

MARINE

Estuaries within south eastern Australia are experiencing sea surface temperatures increasing at a rate of approximately four times the global average[64 65]. This has potentially significant consequences for marine and estuarine species[66]. Temperate locations and cool water species are the most likely to be negatively impacted by increasing water temperature. Increased temperatures may exceed the optimal temperature range of certain species, particularly those with limited thermal ranges.

The warming of the oceans has already resulted in southward range extensions of seaweed, phytoplankton, zooplankton and pelagic fish[67]. The macroalgae of Australia's south coast have retreated 10–50 km south per decade on both sides of the continent[68]. Macroalgae support much of the diversity of marine life and changes to its distribution have devastating impacts on a huge range of species and marine communities[69].

Increasing water temperatures also impact on marine mammals and birds. The ranges of species are likely to move south. Breeding may also be affected for example, little penguins are expected to have increased breeding success in the short term. Although as temperatures continue to rise, success will decline and colonies will be at increasing risk of death due to extreme heat effects and fire[70].

A summary of predicted physicochemical changes in western Victoria's marine environment is presented in Table 5. Further detail on the impact of climate change on marine systems can be found in the Glenelg Hopkins CMA report: Implications of Future Climate for Victoria's Marine Environment[71].

Table 5: Summary of predicted physicochemical changes in Victoria's marine environment[72]

Process / Parameter	Western Victoria		
	2030	2070	2100
Mean Sea Level (m)	↑ 0.15	↑ 0.47	↑ 0.82
Ocean Currents	Predicted minor decrease in transport of the Leeuwin Current by 2100. Flinders Current transport may increase		
Sea Surface Temperature (deg. C)	↑ < 0.5 - 1	↑ < 1 - 2	↑ < 1.5 - 3
Sea Surface Salinity (ppt)	↓ < 0.5	↓ < 0.5	↓ < 0.5
Waves	Potential increase in wave energy due to positive trend in Southern Annular Mode		
Upwelling	Potential increase in Bonney Upwelling due to strengthening south-east winds in summer months		
Acidification (pH)	↓ ~ 0.085 – 0.09	-	↓ ~ 0.29 – 0.3
Runoff Volume (%)	↓15 – 22	↓ 27 – 36	-

The most important current driver of change in marine systems for south eastern Australia is the southern extension of the East Australian Current and the associated warming of the ocean. These changes have resulted in range extension of many marine species[73]. In some cases these provide new opportunities, such as the potential for a snapper fishery to develop in Tasmania. However, they also have potential negative consequences. One pressing challenge is the range extension of the sea urchin *Centrostephanous rodgersii* which has resulted in substantial degradation of kelp beds in some areas and is currently a threat to the rock lobster fishery of Tasmania's east coast.

An additional threat associated directly with increasing atmospheric carbon dioxide is ocean acidification. When carbon dioxide dissolves in the ocean, carbonic acid is formed leading to higher acidity. This increased acidity raises the metabolic energy required for marine organisms to lay down a calcium carbonate shell, resulting in thinner, lighter shells. This in turn can lead to substantial effects on the food chain and marine ecological systems. The effects of acidification are most pronounced in colder waters and a large scientific effort is underway to establish the rate of change in southern ocean systems and potential impacts of these changes[74]. Reduced calcification has been observed in Southern Ocean zooplankton suggesting that ocean acidification is already impacting the biological system[75]. Ocean acidification will negatively impact coastal and marine species, particularly temperate invertebrates such as sea urchins, many of which are 'keystone species'. The outcome of such impacts may result in ecosystem-wide consequences[76].

The impacts of climate change on marine systems are severe and potentially catastrophic if tipping points are reached in terms of ocean warming and acidification. Adaptation will not be possible for the majority of species[77]. However, if warming can be mitigated, adaptation can be supported through the protection and enhancement of land-based systems that influence the marine environment.

There is increasing evidence that land-based management decisions (e.g. dam construction or removal, deforestation, green infrastructure to limit runoff, shoreline hardening, and urban development) will be significant and important interactions affecting adaptation in marine and coastal systems[78]. What happens on the land influences the ocean; reducing the impacts of land management will help to build the adaptive capacity of marine systems.


Vin Gannon

Adaptation Planning

The development of the adaptation pathway for marine as shown in Figure 21 focused on improving catchment-based practices that impact the marine environment. The scope of the pathway aligns with that of the RCS.

A list of measures was completed. Measures were assessed for their adaptation benefit, potential for maladaptation and relevance over time and are shown in Table 34 of Appendix 3. The pathway shown in Figure 21 identifies those measures that are considered current best practice or resilience building, the possibility of the asset requiring transformation and the transition between the two phases.

Adaptation Pathway: Marine

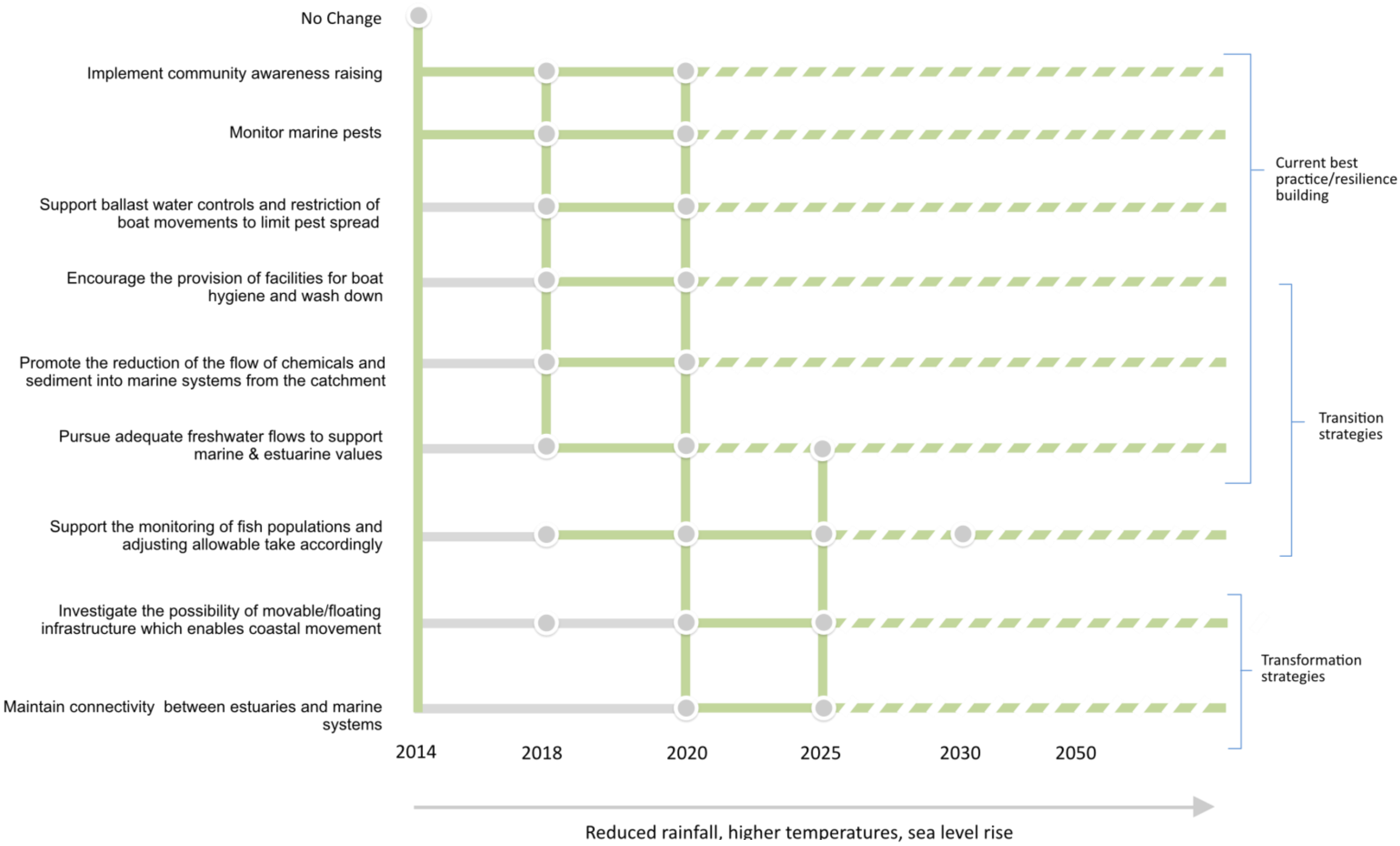


Figure 21: Adaptation pathway for marine

Strategic Direction

The scope of the RCS and this strategy is restricted to the catchment-based threats to marine natural assets[79]. It is recognised that many of the actions for the assets estuaries and coasts will also have benefits for the marine asset. Therefore the actions for the marine environment are restricted to those related to the land-based impacts on marine resilience. Of particular concern is the potential for an increase in marine pests as they migrate southward with increasing temperatures. The control of boat movement and the treatment of ballast water, combined with improved boat hygiene, will help to mitigate this threat. However, long-term monitoring will be essential in the early detection of pest species and the identification of changes to the marine environment that could negatively impact the environment, fisheries and tourism.

Long-term community-based monitoring will help to raise community awareness of the importance of the marine environment and the broader impact of land-based activities. Glenelg Hopkins CMA will promote the reduction in sediment input and sustainable use of chemicals. This action will be an ongoing component to building the resilience of the marine system as well as the rivers and estuaries of the region.

Glenelg Hopkins CMA will continue to support best practice in reducing the impact of catchment-based threats to the marine environment and support opportunities for long-term monitoring and innovative solutions.

Maintaining freshwater flows and connectivity between rivers, estuaries and the marine environment is crucial in building resilience and adaptive capacity. This provides systems with the best chance for maintaining function under a changing climate. The CMA will prioritise action to ensure adequate freshwater flows to support marine and estuarine values.

Strategic Initiatives

- Pursue monitoring of freshwater flows into marine and estuarine environments and the impacts of reductions
- Support and implement actions that reduce catchment-based impacts on the marine environment
- Promote the reduction of sediment reaching the marine environment
- Promote the sustainable use of chemicals within the catchment to reduce the impacts on the marine environment

RCS Objectives: climate ready assessment

The RCS objective for marine does not meet the climate ready criteria as explained in Table 6. Managing catchment-based threats to marine condition will assist with building adaptive capacity. The maintenance of condition into the future may not be possible under a changing climate.

Table 6: Summary of climate ready assessment of RCS objectives for the marine environment

RCS Objective	relevant	revise	Assessment	Revised Objective
Objective 7.1: By 2033 maintain the condition of the marine environment and manage specific catchment-based threats to improve condition where appropriate		✔	The marine environment is unlikely to be able to be maintained under a changing climate. However, the management of catchment-based threats will be essential in building resilience within the marine system and allowing adaptation to change	Reduce specific catchment-based threats to the marine environment

TERRESTRIAL HABTAT

As part of a national assessment of the vulnerability of biodiversity to climate change, terrestrial biodiversity has been identified as one of the most vulnerable assets in the country. Building ecological resilience to give ecosystems the best possible chance to adapt is a key management response[80].

Terrestrial species have already shown responses to observed climate change globally, in Australia and within the Glenelg Hopkins region. Geographic ranges have altered and some species are showing changes to the timing of life cycle processes, such as migration, flowering and breeding. This has resulted in modified genetic and physiological traits and potential mismatches in the timing of plant/pollinator relationships[81].

Identified climate change impacts will also be exacerbated by other existing threats to biodiversity, such as habitat loss and land use change, introduced species and diseases, and altered water resources[82]. Extreme events such as heatwave, drought, flood and bushfire, will also continue to have potentially catastrophic impacts on terrestrial habitats.

As the climate of the Glenelg Hopkins region becomes less suitable for existing vegetation communities, it is likely that there will be a gradual change in species composition and dominance as some species are replaced by others. This will lead to a shift in the distribution and structure of the community. While a lag could be expected between the climate shifting and the community response, some changes may develop earlier in response to the increased occurrence of extreme events such as floods, droughts and bushfire. Tropical invasive species are expected to expand their ranges with potential negative impacts for the Glenelg Hopkins region, while cool-climate invasive species are more likely to contract[83].

One of the few habitat types for which there is information on the impact of climate change is eucalypt woodlands and grassy woodlands. The climatic variable with the strongest influence on these systems is moisture. It is likely that a drying climate will result in a decline in tree cover as well as an increase in annual grasses and a decrease in perennials.

Research completed through the National Climate Change Adaptation Research Facility[84] indicates that to reliably improve future landscapes for biodiversity relative to current ones, native vegetation cover needs to be restored to approximately 30%. At least this amount of native vegetation is required to maintain biodiversity. Although the total amount of vegetation restoration is more important than the detailed spatial configuration, it is recommended that effort is concentrated in small priority areas to achieve approximately 30% cover[85].

Revegetation will play a key role in improving the extent, quality and connectivity of terrestrial vegetation in the Glenelg Hopkins region. Although it has been recognised that the methods currently available to managers and volunteer groups are inadequate to reliably assess if particular species and provenances will persist over the next hundred years[86]. For example, for many eucalypt species, future climatic domains are projected to fall entirely outside their current climatic ranges within a few decades. Even widely distributed species may be vulnerable in particular areas near the hotter or drier extremes of their current distributions[87].

Although some species may be lost to the region, there are other species for which the Glenelg Hopkins region may become suitable. For example, the river red gums of the Glenelg Hopkins region are in the cooler and wetter area of their range and it is possible that the region may become a refuge for river red gum and associated species. It is necessary that what remains is protected and enhanced and where possible connections between remnant patches are formed.

Connectivity is necessary to allow greater movement of species through the landscape in response to change. For forests, in particular, it is also important that mature trees are protected and that replacement trees are available to provide hollows over time. The presence of hollows, old logs and dead trees is fundamental for providing habitat, species protection and maintaining overall diversity. This will become increasingly important under a changing climate.

Attempting to maintain the status quo by conserving the current structure and composition of communities in the Glenelg Hopkins region may not be a viable management option in the long term. A shift in management focus towards maximising the resilience of communities and maintaining ecosystem function is required. This approach fits well within a risk management framework because there will always be uncertainty associated with future climate projections. Current condition is likely to be an important predictor of the long-term viability of a community, with those in better condition more resilient to change in the short term, and more adaptable in the long term due to their greater genetic, floristic and structural diversity.

For future revegetation projects a shift in focus is required from planting species specific to the Glenelg Hopkins region to planting species or ecotypes expected to be more tolerant of new conditions. Additional research is required to support this change.

Vulnerability

Vulnerability mapping has been developed for the terrestrial habitat asset using a range of factors for each component, including exposure, sensitivity and adaptive capacity, as listed in Appendix 2. The components of exposure, sensitivity and adaptive capacity and their relationship to vulnerability are illustrated in Figure 6. The maps have been developed using RCP8.5 which represents a high-emission scenario, for which carbon dioxide concentration reaches about 940 ppm by the end of the twenty-first century[88].

The vulnerability modelling for terrestrial habitat (Figure 22, Figure 23, Figure 24) shows a significant increase in vulnerability over time. By 2090 the majority of the region shows at least moderate vulnerability with only small patches within public land remaining low. The region's terrestrial habitat experiences a distinct increase in vulnerability from 2050 to 2070. The drivers behind this change vary across the catchment. The area between Ararat and Mortlake and the area bordering South Australia are both sensitive to the reduction in rainfall and are considered to have a low adaptive capacity. In contrast the Portland/Heywood district is highly sensitive to the increase in maximum temperature.

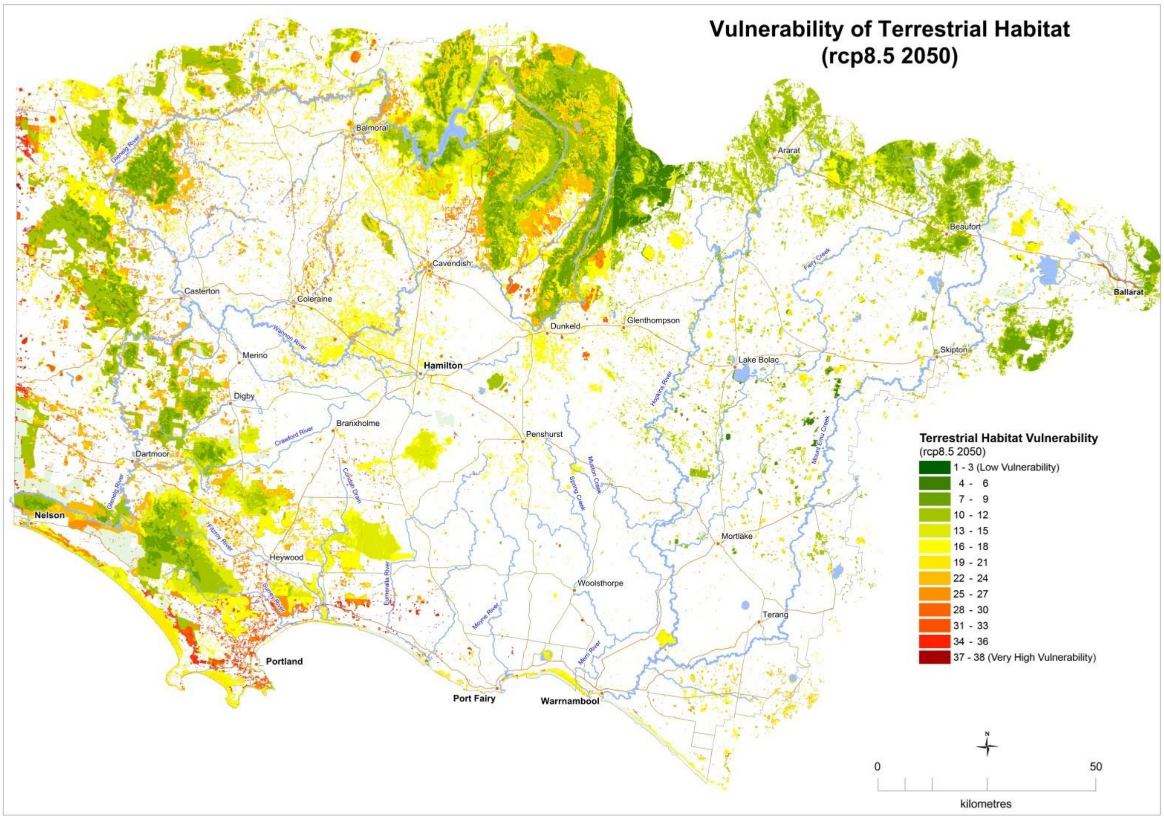


Figure 22: Vulnerability of terrestrial habitat 2050

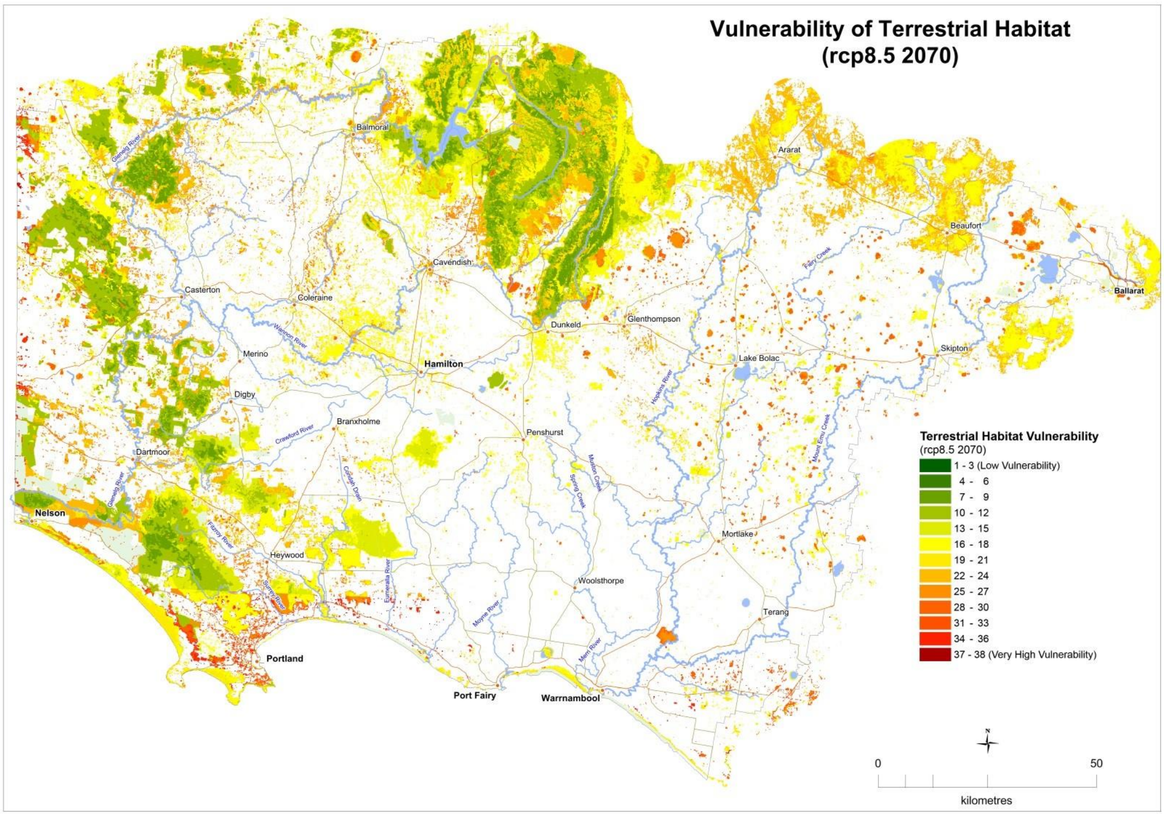


Figure 23: Vulnerability of terrestrial habitat 2070

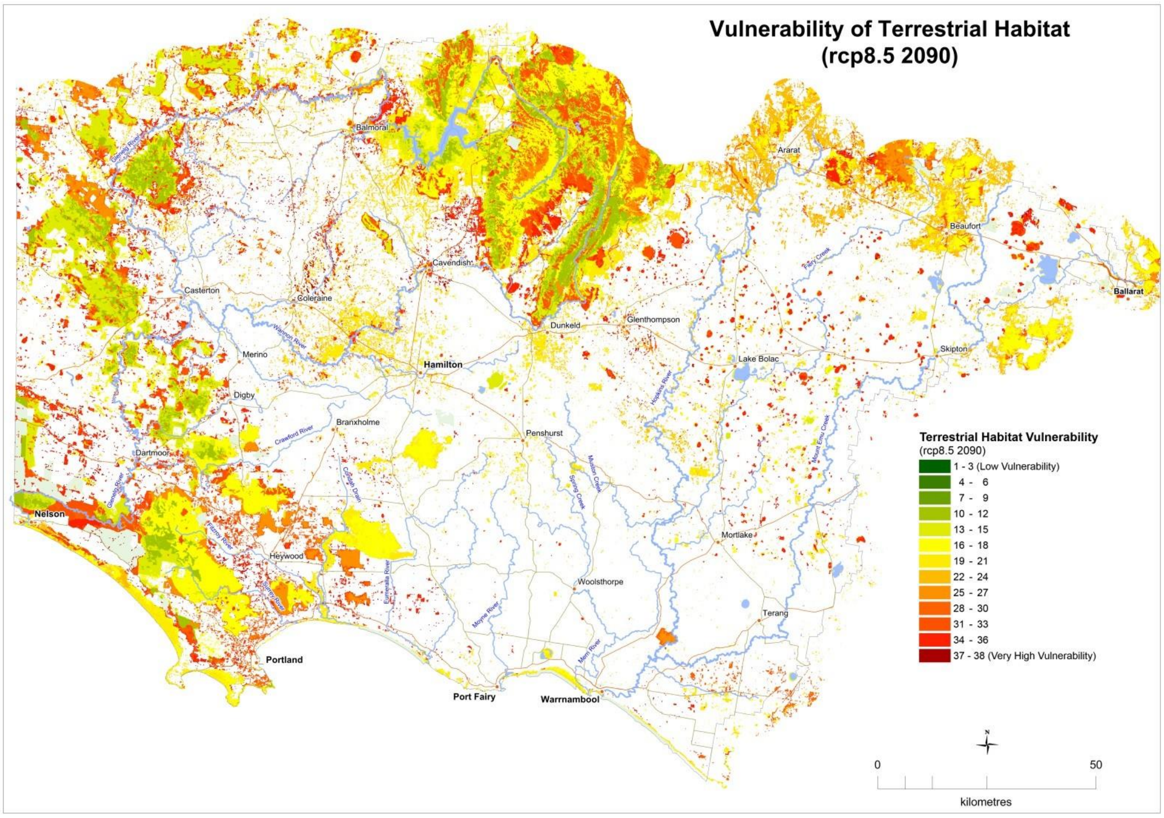


Figure 24: Vulnerability of terrestrial habitat 2090

Adaptation Planning

The development of the terrestrial habitat pathway as shown in Figure 25 was directed towards improving biodiversity and connectivity as essential components in building adaptive capacity in response to climate change. It was recognised that current best practice activities are already contributing to an increase in the resilience of terrestrial vegetation communities. In the long term, the changing climate will make many areas unsuitable for current vegetation and the maintenance of habitat will depend upon the ability of species to move in response to changing temperature and rainfall patterns. It is unlikely that habitats will be able to be maintained in their current patterns or species assemblages. However, structure and function may be able to be maintained. This will depend on building resilience and biodiversity, facilitating the protection and enhancement of functional redundancies and improving connectivity throughout the landscape.

A list of measures was completed. Measures were assessed for their adaptation benefit, potential for maladaptation and relevance over time and are shown in Table 35 of Appendix 3. The pathway identifies those measures that are considered current best practice or resilience building, the possibility of the asset requiring transformation and the transition between the two phases.

Adaptation Pathway: Terrestrial Habitat

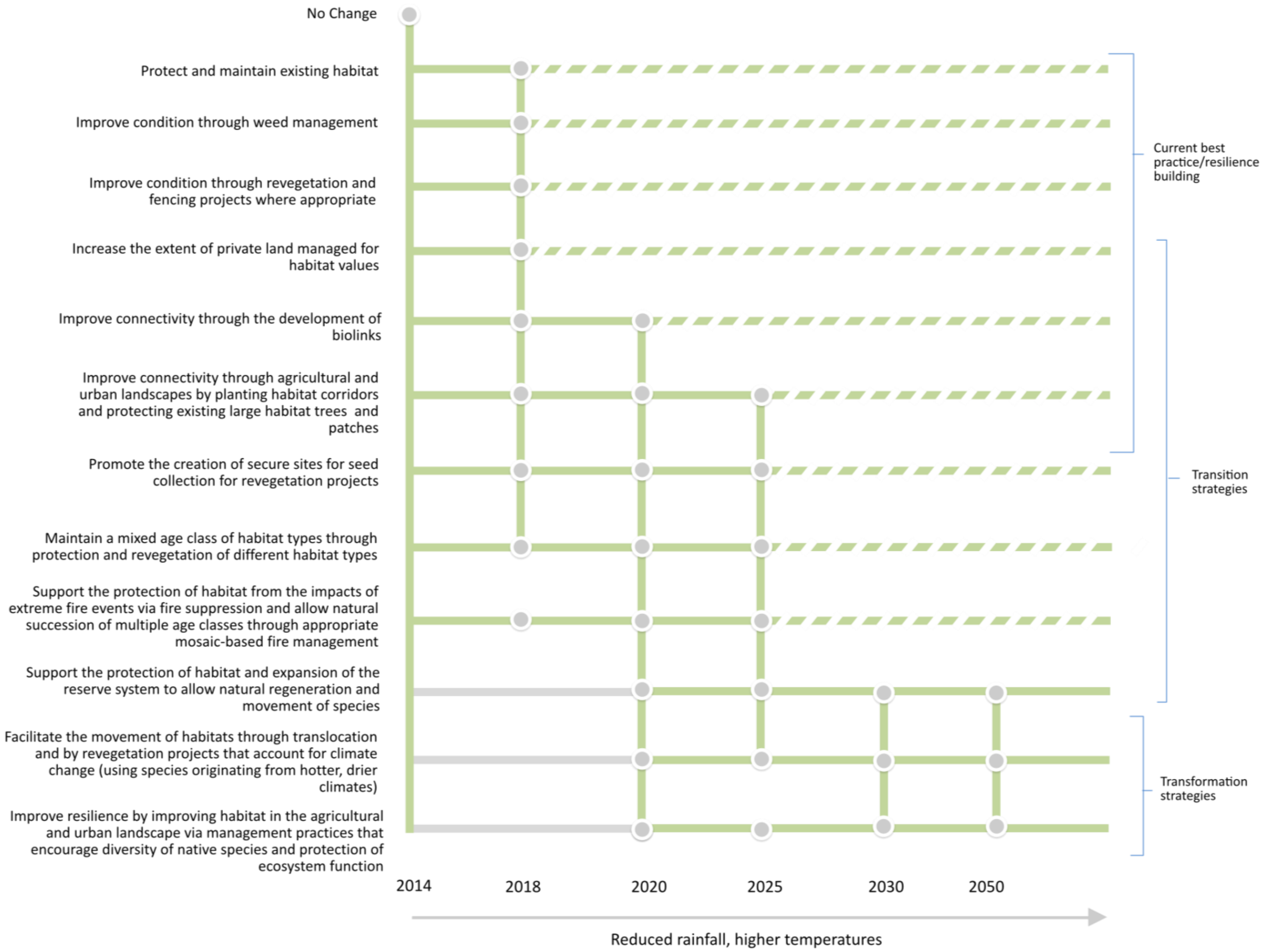


Figure 25: Adaptation pathway for terrestrial habitat

Strategic Direction

The key to building the resilience of terrestrial habitat and allowing adaptation in response to climate change is in addressing existing threats and improving connectivity between patches of native vegetation. Connectivity is fundamental in allowing the natural dispersal of species and to allow the best chance for terrestrial vegetation to adapt. Glenelg Hopkins CMA will continue to support programs that address current threats and focus on building connectivity in priority areas.

Genetic variation is also a key component for the adaptation of terrestrial vegetation. Current revegetation and enhancement projects may not be suitable under a changing climate. With many species likely to be outside their climatic range in the future, species lists for revegetation need to be developed with reference to the changing climate and with long-term change in mind. Glenelg Hopkins will prioritise refining current planting policies to incorporate climate change considerations.

With an increasing risk of extreme fire events it is also critical that priority habitat and refuge areas are protected from fire. Refuge modelling and mapping will become increasingly important in future planning. Long-term monitoring is also a critical component in recording changes to species' distributions, habitat quality and extent, and identifying emerging weed species. Community programs such as Landcare have a major role to play in both collecting long-term data and in facilitating adaptation through the protection of existing remnants and the revegetation of strategic buffer zones, corridors and biolinks to improve connectivity. The CMA will facilitate the delivery of on-ground outcomes through implementing programs with community, landholders and Landcare.

Glenelg Hopkins CMA will continue to support best practice in terrestrial habitat protection and revegetation, with a particular focus on improving connectivity and diversity. Future projects and programs and strategies will be developed in alignment with the policy statements and using an adaptive planning approach.

Strategic Initiatives

- Protect existing high value habitat through managing existing threats
- Build connectivity through the establishment of biolinks and corridors in priority areas
- Support the establishment of biodiverse carbon plantings with multiple environmental benefits
- Revise current revegetation species planting policies to incorporate climate change considerations
- Support the identification of fire refuge areas
- Implement habitat protection and enhancement programs through partnerships with landholders, Landcare and the community

RCS Objectives: climate ready assessment

The RCS objectives for terrestrial habitat will significantly contribute to building resilience and adaptive capacity. While maintaining the current extent of terrestrial habitat types will not be possible in the long term, overall habitat extent may be able to be maintained and even extended, although the type of habitat will change in response to changing conditions. A summary of the assessment of RCS objectives for terrestrial habitat is presented in Table 7.

Table 7: Summary of climate ready assessment of RCS objectives for terrestrial habitat

RCS Objectives	relevant	revise	Assessment	Revised objective
Objective 8.1: Maintain extent and improve condition of terrestrial habitat	✔		Maintaining extent and improving condition will be essential to facilitate adaptation as species shift and alter in relation to changing temperature and rainfall	n/a
Objective 8.2: Improve connectivity of habitat for species populations and communities	✔		Connectivity is key to allow for the migration of species in response to change	n/a
Objective 8.3: Public land is managed as the core of resilient ecosystems	✔		This is crucial to allow for adaptive capacity and refugia for species in responding to change and extreme conditions	n/a
Additional objective				Develop species planting guidelines with climate change considerations

SPECIES, POPULATIONS AND COMMUNITIES

Climate change (in particular changes to carbon dioxide concentrations, temperature and precipitation) will affect the basic physical and chemical environment underpinning all life. Species will be affected individually by these changes, with flow-on effects for the structure and composition of current ecological communities. Ecosystem function and the services they provide will also be effected.

Climate change will result in shifts in suitable habitat for species, requiring species to move in order to adapt and survive. The ability of species to move in response to climate change within the Glenelg Hopkins region depends on their ability to disperse and the availability of suitable habitat. Improved connectivity through linking existing remnant vegetation provides many communities, species and their genes with the ability to move throughout the landscape. The movement of species is far more difficult to facilitate in coastal areas as species distributions are pushed southward and sea level rise and coastal erosion push northward limiting the available habitat and resulting in 'coastal squeeze'.

Responses are likely to be species-specific due to complex interactions between changes in rainfall and temperature and the different thermal thresholds of species. Some species will be more vulnerable than others to extinction. Species may not be able to shift to areas with suitable climatic conditions due to being located in fragmented habitats, or because of their limited dispersal ability. Species with small, isolated or fragmented ranges, or those with low genetic variation and specific thermal requirements, will be more vulnerable and local extinctions are likely. Species currently listed as threatened are most vulnerable to extinction.

There are a range of factors that, in combination, form a cascade of responses and feedbacks within systems. The complexity of the effects of changes in climate on biotic interactions means it is difficult to predict responses. It is certain that overall declines in biodiversity will occur, and ecological monitoring will be essential in improving understanding of these processes. This will enable the development of strategies for effective biodiversity conservation and adaptive management[89].

Because the rate of climate change is likely to outpace the ability of most species to adapt, changes in the distribution of fauna and flora are expected to be a major response to climate change. Fauna which are sensitive to climatic conditions, particularly temperature, are generally expected to move poleward, towards higher latitudes and up-slope to higher altitudes in response to increasing temperatures. An average global shift poleward of 6.1 km per decade has been estimated[90].

Increasing urbanisation, agriculture and land use change will potentially act as barriers to movement of species. If species are unable to cross the region's urbanised and modified habitats in response to the changing climate they are likely to become extinct. The loss of marginal habitats including the coastal fringe is likely and interactions between a changing climate and habitat loss and change will result in species extinctions and an increasingly homogenised flora and fauna[91].

To facilitate the best possible chance for species and community adaption, remaining habitats must be protected and managed, degraded habitats restored and connectivity between habitats increased. It is preferable to allow for natural distribution shifts and adaptation; however, genetic translocation may become an option. The movement of individuals and therefore genes could increase the genetic diversity and therefore the resilience of species[92]. Assisted colonisation may also be possible for a small number of vulnerable species[93]. This is not only an issue for species currently within the Glenelg Hopkins region but also for species whose climatic envelope is not currently in the region, but will shift to be within the region in the future[94].

Changes in life cycle events (phenology), such as flowering, emergence, breeding and migration, have been identified as one of the most important impacts of climate change on biodiversity. Such events are important determinants of species distributions, species interactions and the structure and function of all ecosystems. The response of species to climate in Australia has been predicted to occur on average four days earlier per decade[95]. There is a lack of long-term monitoring of the timing and nature of species life cycle events. It is not yet possible to predict how the life cycles of specific species might change within the Glenelg Hopkins region.

Climate change impacts are likely to be exacerbated by acting in combination with other threats to biodiversity, such as habitat loss, degradation and land use change, introduced species and diseases, and altered water resources. If native species and communities are to have the best chance of adapting, all threats must be addressed simultaneously.

Vulnerability

Modelling the vulnerability of species, populations and communities to climate change needs to be undertaken at the appropriate scale and is an intensive process. The modelling presented in the other asset chapters covers the range of habitats available in the Glenelg Hopkins region. From a landscape perspective the vulnerability of assets and habitats is a direct indicator of the vulnerability of populations and communities. As the vulnerability of species is complex and modelling at this scale is rare, vulnerability was unable to be modelled or mapped for this asset.

Vulnerability modelling for species, populations and communities is not essential for the development of adaptation pathways at the asset level. Much is known regarding the general principles of building resilience and adaptive capacity at this scale. Regional experts relied upon existing knowledge and local experience in developing the following adaptation pathway.

Adaptation planning

Similar to the terrestrial vegetation pathway, the species, populations and communities pathway in Figure 26 recognises the importance of maintaining and increasing current best practice activities. This builds resilience and reinforces the importance of both biodiversity and connectivity. Many of the actions identified in previous and subsequent sections will also be appropriate for species, populations and communities. In building the resilience of species and facilitating adaptation to a changing climate, the restoration of ecological functions will be critical.

The assisted colonisation of species is a controversial issue and may or may not be appropriate under different climate scenarios. However, it is an important option to identify for discussion. A list of measures was completed. Measures were assessed for their adaptation benefit, potential for maladaptation and relevance over time and are shown in Table 36 of Appendix 3. The pathway identifies those measures that are considered current best practice or resilience building, the possibility of the asset requiring transformation and the transition between the two phases.

Adaptation Pathway: Species, Population and Communities

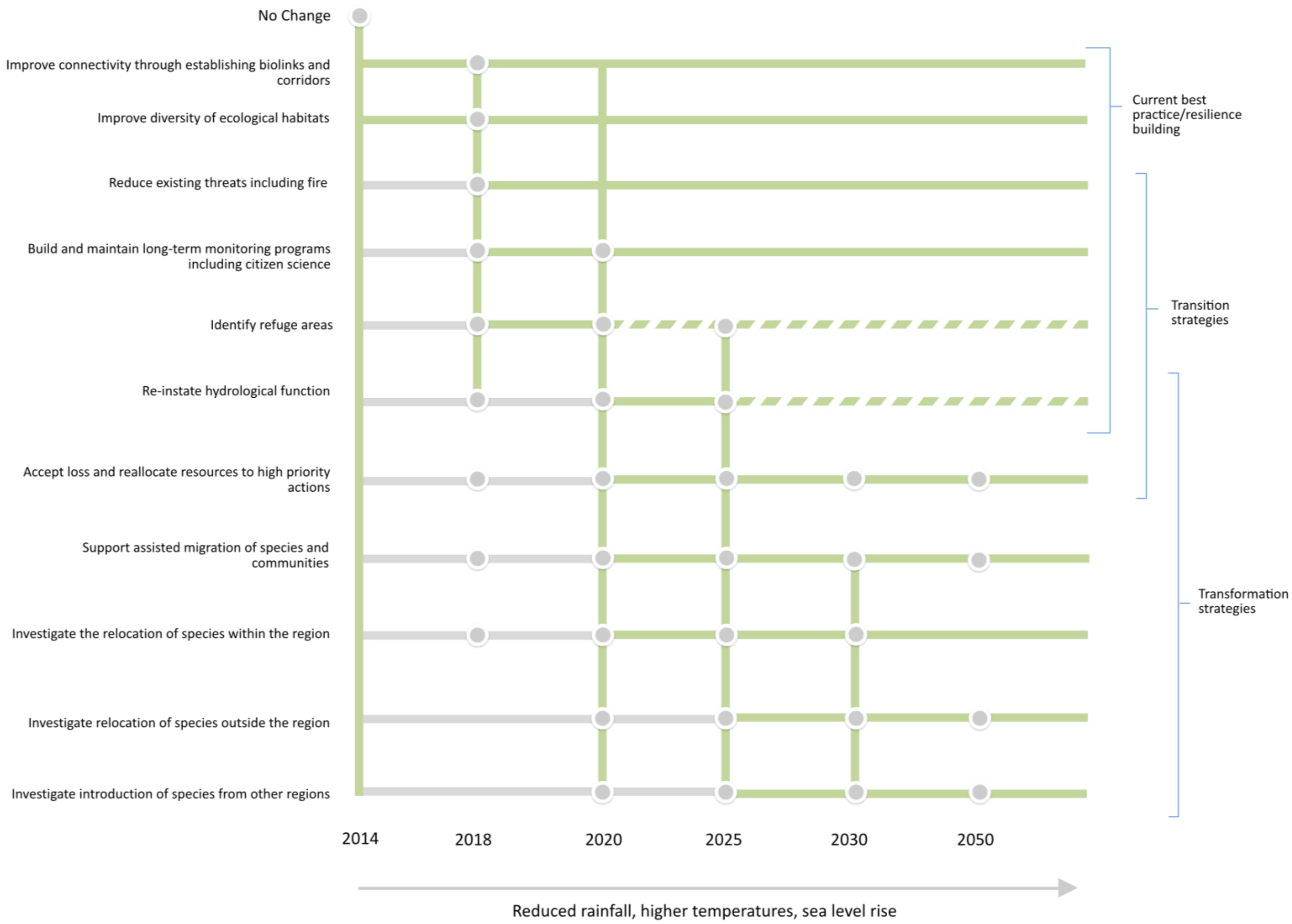


Figure 26: Adaptation pathway for species, populations and communities

Strategic Direction

Building the resilience of the Glenelg Hopkins region's ecological systems will help give species, communities and populations of native flora and fauna the best chance of adapting to a changing climate. However, it is certain that many species will be at risk of extinction due to the combined impacts of climate change and the existing threats caused by land use change and the erosion of resilience and adaptive capacity.

Glenelg Hopkins CMA will support building the resilience and adaptive capacity of species, populations and communities through landscape scale revegetation and restoration programs and a shift to focusing on prioritising ecological system function.

In preparation for change, the concept of 'provenance' and returning ecosystems to pre 1880s 'natural' states needs to be blended with new, novel components and systems. This will require further research into the response of species and communities to the change in regional climate. Glenelg Hopkins CMA will adopt a planning and prioritisation process that focuses on maintaining function, functional redundancies and genetic diversity[96]. Although existing best practice conservation practices undertaken by Glenelg Hopkins CMA will continue to form the foundations for future management, discovering new and innovative approaches to adapting to climate change may require acceptance of change and loss and the possibility of novel ecosystems[97].

Maintaining species diversity and preventing species loss and extinction will remain the objective of the CMA. For individual species, future change may be too rapid and too extreme for them to adapt without intervention. For many species the fragmented landscape will become impossible for them to cross. Assisted migration may become the only option for survival. A range of constraints may restrict the number of species that can be supported and a triage system and a method for the prioritisation of key species may need to be developed[98]. Triage is a contentious issue and should only occur as a last resort and after rigorous debate between all stakeholders involved.

Glenelg Hopkins CMA promotes current best practice in biodiversity management and protection, and will continue to support in situ conservation methods. By improving habitat quality, diversity and connectivity, threatened species are given the best chance to adapt without intervention. In accordance with the policy statements, it is recognised that loss will be inevitable in the long term. Monitoring of long-term change is encouraged and it is recognised that future planning will need to address issues such as the triage and translocation of species.

Strategic Initiatives

- Support landscape scale revegetation and restoration programs to increase resilience and adaptive capacity
- Adopt a planning and prioritisation process that focuses on maintaining function, functional redundancies and genetic diversity
- Improve habitat quality, diversity and connectivity
- Implement revegetation that buffers current remnant vegetation
- Support research into the responses of species and communities to climate change

RCS Objectives: climate ready assessment

The RCS objective for species, populations and communities does not meet the climate ready criteria, as explained in Table 8. Although it remains an important objective for threatened species in the short term.

Improving the health of key populations may not be possible under a range of possible climate change scenarios in the long term, but is important in the short term in building the adaptive capacity of species. Threatened species and communities are among those assets most likely to be impacted by climate change and it may not be possible to improve the health of populations in situ.

Table 8: Climate ready assessment of RCS objectives for species, populations and communities

RCS Objective	relevant	revise	Assessment	Revised objective
Objective 9.1: Improve the health of key populations of threatened species and communities	✔	✔	This objective will become increasingly difficult under a changing climate. Improving the health of key populations will give them the best possible chance to adapt and will improve both species and genetic diversity The objective remains relevant under the timeframe of the current RCS, but will require revision for the next RCS	Maintain the health of key populations of threatened species and communities

SOIL AND LAND

For the Glenelg Hopkins region, climate change modelling and projections indicate that increasingly hotter and drier conditions can be expected. Temperature is expected to increase in all seasons with an increasing number of hot days and fewer very cold days overall. Average annual temperatures are projected to rise by between 0.5 and 1.1 ^{o}C by 2030. Winter rainfall is likely to decrease and summer rainfall expected to increase. Despite a decrease in winter rainfall by up to 30% by 2090, the intensity of extreme rainfall events is likely to increase. Because of the natural variability in rainfall across the region, the overall trends may be masked for decades to come, particularly in summer[99].

Despite these changes, the impact of climate change on agriculture is expected to be less damaging to south west Victoria than other parts of the state[100]. Temperatures are expected to remain moderate while rainfall is anticipated to remain adequate in the medium term, particularly in the region's south[101]. It is likely that the area most suitable for grain production will move southward due to the drying of the region's climate, increases in international prices, raised bed technology and the decline in the region's wool industry[102].

The Glenelg Hopkins region may become more attractive to agricultural producers in northern Victoria, who may experience more negative production impacts due to climate change and wish to relocate. An increase in cropping has already occurred within the region. From 1990 to 2010 an average of 12,000 ha per year of grazing pastures were converted to cropping[103].

Plant production in the Glenelg Hopkins region is likely to be affected by an increase in the number of hot days, resulting in poor fertilisation when occurring at flowering time[104]. The likely response is a change to sowing crops earlier and applying more nitrogen at sowing. Although an effective productivity response, this practice could act against greenhouse gas mitigation. Pasture-based systems in the Glenelg Hopkins region such as dairy, beef cattle, sheep and lambs are likely to be affected by a decrease in pasture production and reliability[105]. This decrease may have implications for the region's feed management systems, with a potential increase in dependence on cool season production, grain feeding and stored fodder[106].

Average annual runoff into the region's waterways is expected to decrease. This will have significant impacts for agricultural industries. It is likely that the proportion of years when no water is available for agricultural diversion will increase and the potential for on-farm water supplies to be exhausted will rise[107].

Climate has a direct impact on soil health and has its most severe impacts in extremes of dryness leading to wind erosion and, in extremes of wetness, leading to sheet, rill and gully erosion. Soil erosion is likely to be exacerbated throughout the Glenelg Hopkins region due to an overall reduction in rainfall in combination with increases in intense rainfall events occurring on dry, denuded soils. In combination, drier soils, reduced vegetation cover and more intense rainfall will present significant challenges to soil conservation even with moderate climate change[108].

Soil health is also linked to climate benefits on a global scale because soils can store carbon, leading to improved soil quality and reduced greenhouse impacts[109]. Carbon within the terrestrial biosphere can behave either as a source or sink for atmospheric carbon dioxide depending on land management, thus potentially mitigating or accelerating the greenhouse effect[110]. Soil carbon in the region is expected to decrease under climate change due to decreased net primary production and conversion of pastures to cropping[111]. Any gains in increased efficiency of plant water use due to elevated carbon dioxide levels are likely to be outweighed by increased carbon mineralisation after episodic rainfall and reduced annual and growing season rainfall.

Changes in average temperatures and rainfall patterns in the Glenelg Hopkins region will also influence soil organic matter. This in turn will affect important soil properties such as aggregate formation and stability, water holding capacity, and soil nutrient content[112]. Increasing the amount of carbon sequestered in soil has the potential to contribute greatly to mitigation and adaptation in response to climate change.

Increasing soil carbon is possible through the management of arable and degraded soils to increase carbon sequestration and by increasing plant diversity. Increased diversity enhances community-level carbon dioxide uptake and below ground allocation to roots and mycorrhizal fungi, which is a key mechanism governing carbon sequestration in soil[113]. Increasing the cover and diversity of species has multiple benefits and contributes to the increased resilience and adaptive capacity of both agricultural and ecological systems.

Soil biology and microbial populations are also expected to change under conditions of elevated carbon dioxide and changed moisture and temperature regimes. As soil biology regulates nutrient dynamics and many disease risks, nutrient availability to crops and pastures could change, as could the exposure to soil-borne diseases[114].

While carbon fertilisation and certain climatic changes could benefit some crops in some regions of the world, its overall impacts are expected to be negative, threatening global food security[115]. Without effective global mitigation through a reduction in greenhouse gas emissions, there will be major declines in agricultural production across much of Australia by mid-century[116].

Considerable research has been and is being undertaken, to assess the potential impacts and adaptation strategies for Australian food and fibre producers under various climate change scenarios. The publication, Adapting agriculture to climate change, provides a comprehensive reference source covering climate change impacts and adaptation research into fisheries, forestry and key agricultural industries in Australia[117].

Vulnerability

Vulnerability mapping has been developed for the soil and land asset using a range of factors for each component including exposure, sensitivity and adaptive capacity, as listed in Appendix 2. The components of exposure, sensitivity and adaptive capacity and their relationship to vulnerability are illustrated in Figure 6.

The vulnerability modelling (Figure 27, Figure 28, Figure 29) for soil and land shows a significant increase in vulnerability in several parts of the catchment over time. In particular coastal areas become very highly vulnerable by 2050, as does the far north west of the region. The drivers for this change are the sensitivity of the soil types to the reduction in rainfall and the increase in November to April temperatures. The majority of the catchment remains moderately vulnerable until 2090.

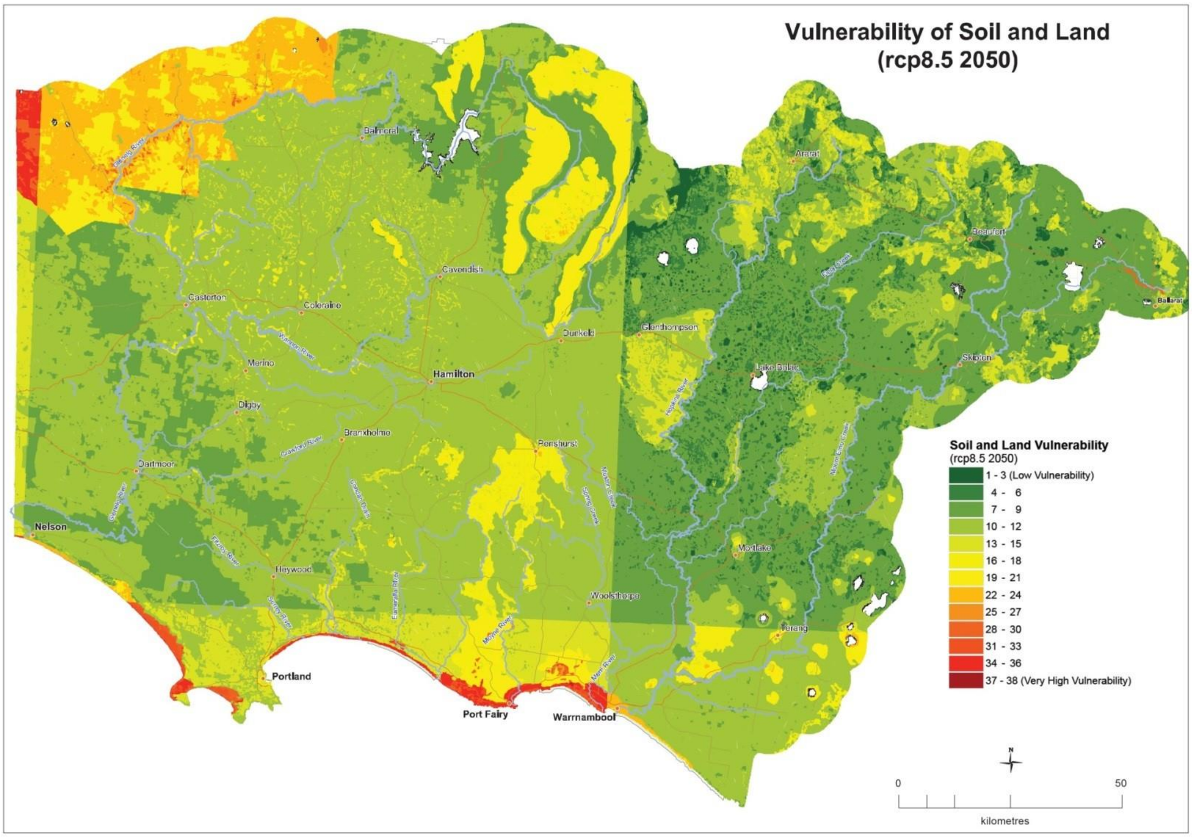


Figure 27: Vulnerability of soil and land 2050

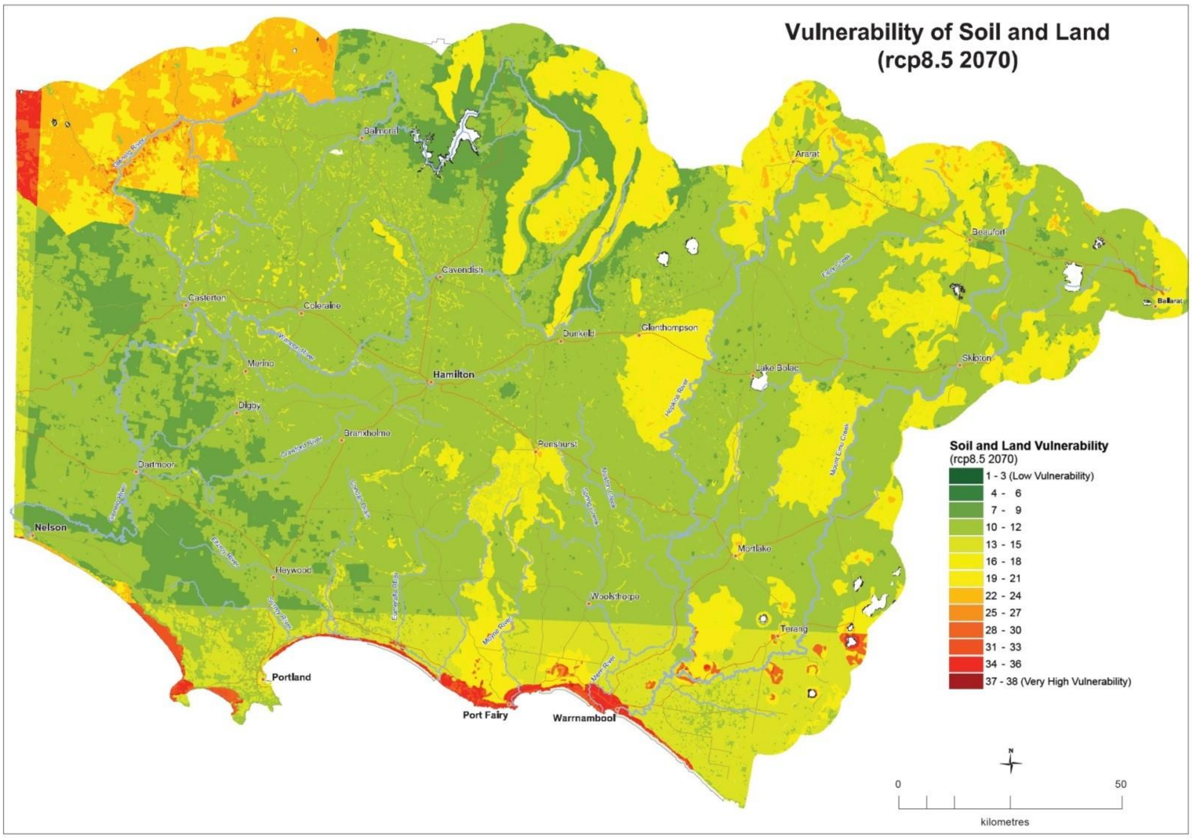


Figure 28: Vulnerability of soil and land 2070

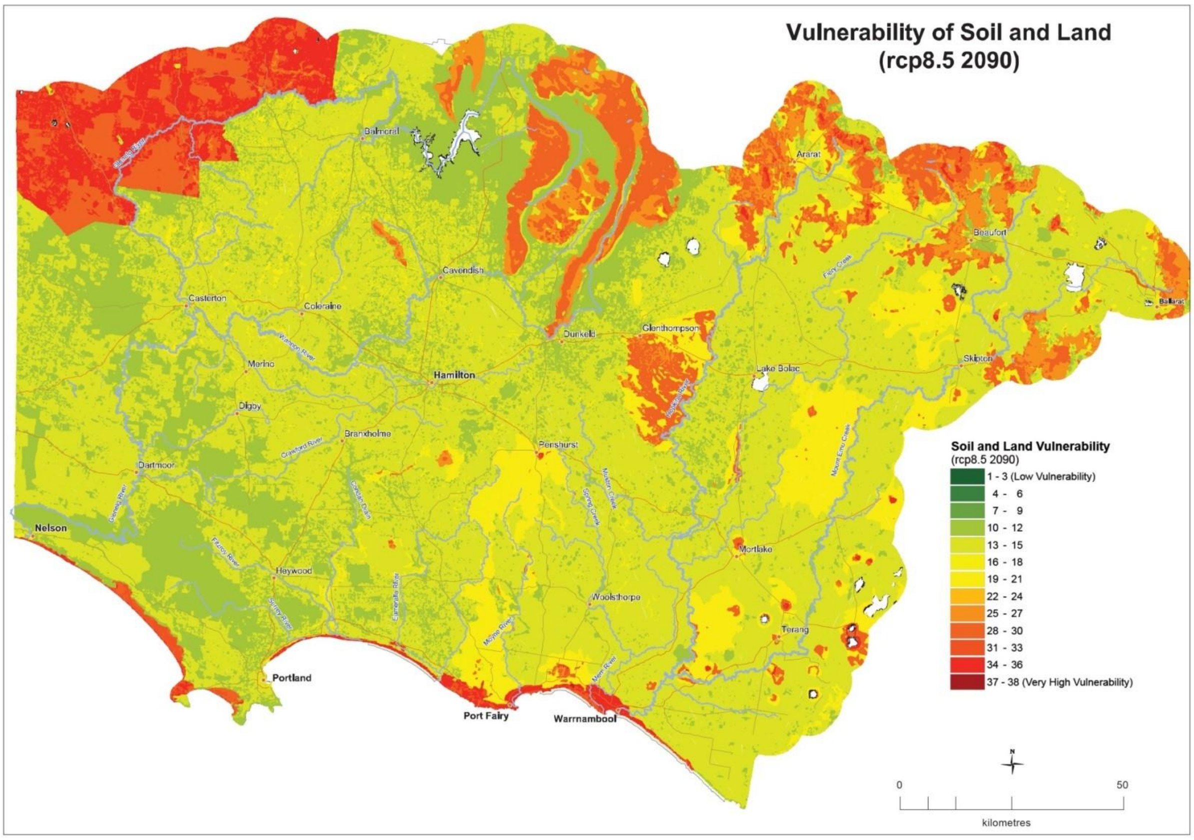


Figure 29: Vulnerability of soil and land 2090

Adaptation Planning

The adaptation pathway for soil and land illustrated in Figure 30 has been developed in consultation with internal and external stakeholders. The soil and land pathway focuses on private land as the majority of the areas identified as highly vulnerable are outside of the reserve systems. The exception to this is coastal soils, which are included in the coastal asset.

The main concern for the conservation of soils in the region is maintenance of cover. It was considered that current best practice management would greatly increase the adaptive capacity of soils and therefore the focus should be on increasing the uptake of such measures. Each of the measures listed were considered to contribute to adaptation and to remain relevant over time under a changing climate.

The pathway identifies measures that are considered current best practice or resilience building, the possibility of the asset requiring transformation and the transition between the two phases. A list of measures was completed. Measures were assessed for their adaptation benefit, potential for maladaptation and relevance over time and are shown Table 37 of Appendix 3.

Knowledge and awareness was identified as the major constraint in the uptake of best practice by regional landowners. A key action in the conservation of soils under a changing climate is to improve landowner awareness and the uptake of best practice soil management.

Adaptation Pathway: Soil and Land

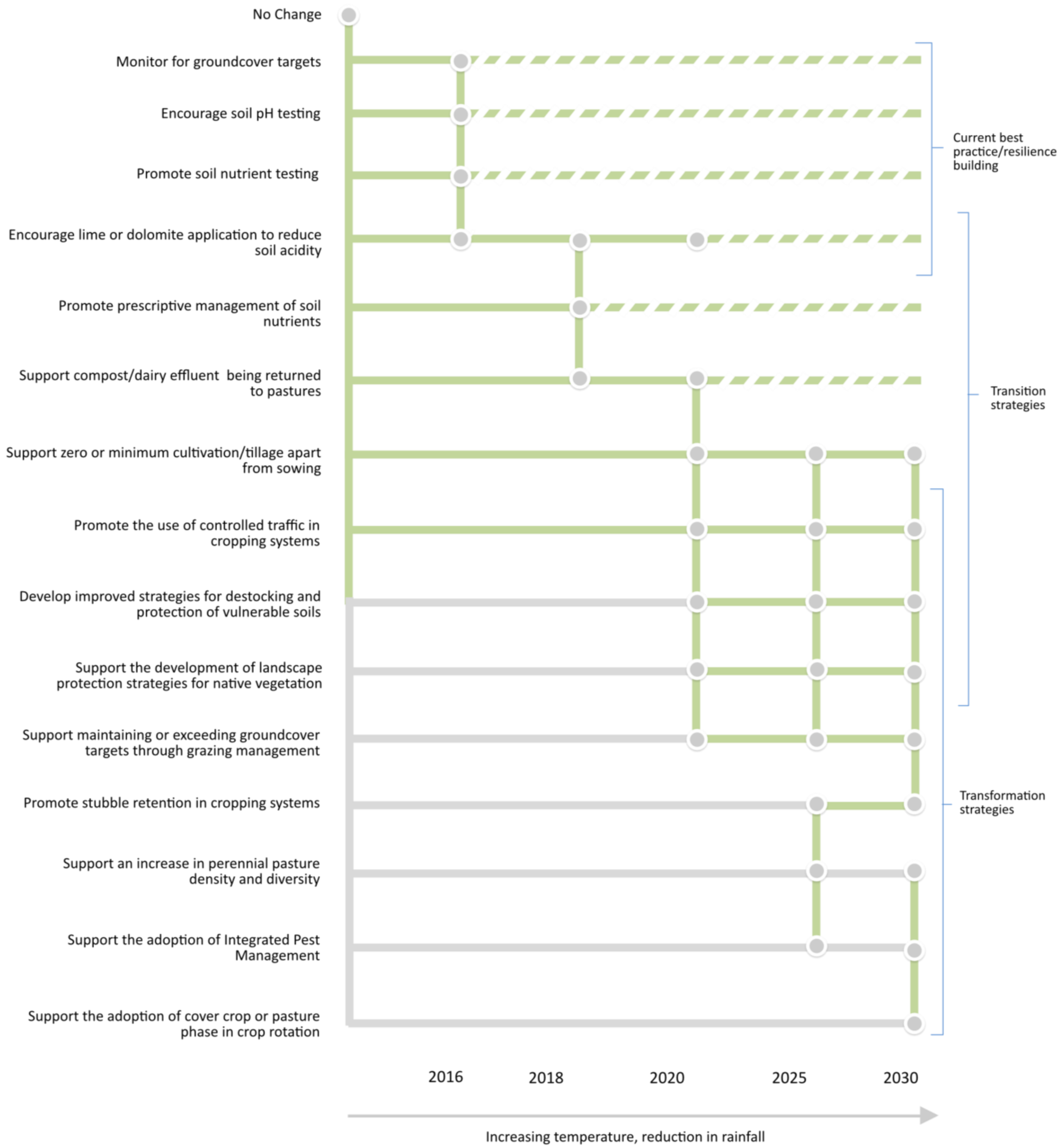


Figure 30: Adaptation pathway for soil and land

Strategic Direction

Increasing the adaptive capacity of soils is dependent on building the resilience of soils in response to increased temperature, decreased annual rainfall and an increase in extreme drought and rainfall events. The major contributor to soil resilience is an increase in soil carbon. An increase in soil carbon will protect soils from drying and from associated erosion from wind or extreme rainfall events.

Increased diversity of pasture, crops and native plants and animals will be crucial in allowing adaptation throughout the Glenelg Hopkins landscape. Glenelg Hopkins CMA will continue to promote the increased adoption of current best practice in agriculture and soil management. Supporting improved nutrient management and an increase in soil cover will be important in achieving a long-term transition towards management for mutual ecological and agricultural benefits. Regardless of agricultural process or soil type, increasing groundcover is an achievable and realistic action to build the resilience of soils and allow for adaptation in response to a drier and warmer climate. Increasing groundcover remains relevant under all possible climate scenarios. It provides additional benefits to biodiversity and improves ecosystem services such as supporting soil formation and the provision of soil structure and marketable goods[118].

It has been recognised that many of the actions required to improve the resilience of soils would also provide additional benefits to the resilience of the entire ecological system and provide an improved matrix for the distribution and adaptation of species throughout the landscape. For example, by maintaining cover and managing nutrient and pesticide use, the hostility of the agricultural landscape to native species is reduced allowing species more opportunity to move and adapt in response to a changing climate.

Glenelg Hopkins CMA will continue to encourage best practice in soil management and will promote actions that contribute to maintaining groundcover and reducing soil disturbance as identified in the Glenelg Hopkins Soil Health Strategy 2014–2019[119]. Opportunities to work with partners to encourage land management practices that protect and enhance the diversity of native species and ecosystem function will be pursued.

Strategic Initiatives

- Monitor land use change
- Support practices that increase groundcover
- Promote an increase in pasture, crop and native plant diversity
- Support the adoption of sustainable nutrient and pesticide management
- Support minimum and zero till cropping practices
- Support research into emerging soil carbon capture and storage methods

RCS Objectives: climate ready assessment

The RCS objectives for soil and land will all contribute to an increase in adaptive capacity and are relevant to the timeframe of the document. In particular reducing existing threats will become increasingly important in the short term and will reduce the impact of climate change in the longer term.

The achievement of objective 10.4 in Table 9 could help to support the transformation of ecological systems to become increasingly adaptive and resilient under climate change. A summary of the full assessment of RCS objectives for soil and land is presented in Table 9.

Table 9: Summary of climate ready assessment of RCS objectives for soil and land

RCS Objective	relevant	revise	Assessment	Revised objective
Objective 10.1: An improvement in soil condition as measured by key indicators by 2033	✓		Considerably more difficult under climate change but also increasingly important for adaptation	n/a
Objective 10.2: An increase in the area of soils managed within their capability		✓	'Capability' of soils will change in response to the changing climate	Increase uptake of adaptive and sustainable land management practices by agricultural enterprises
Objective 10.3: By 2033 reduce the impact of soil-based threats, including salinity and erosion, on waterways and wetlands as measured by improved ISC and IWC scores (turbidity and EC)	✓		Will become increasingly important under changing climate, providing multiple benefits and improving adaptive capacity	n/a
Objective 10.4: By 2033 soils are managed for protection and enhancement of the beneficial ecosystem services provided by soils	✓		Fundamental in supporting the adaptation of soils to a changing climate and contributes to transformational change	n/a

RCS Objectives and Measures That Relate to All or Multiple Asset Themes

The RCS objectives that relate to all or multiple assets are assessed in Table 10. Two of the objectives are not considered climate ready and have been revised.

Table 10: Summary of climate ready assessment of RCS objectives related to all or multiple assets

RCS Objectives	relevant	revise	Assessment	Revised Objective
Objective 1.1: Protect and improve the region's waterways, wetlands and estuaries	✔	✔	Remains an important action and contributes to adaptive capacity in the short term. However will require revision to meet the climate ready adaptation propositions	Protect the region's waterways, wetlands and estuaries and improve where appropriate
Objective 1.2: Reduce the impact of pest plants and animals on the region's natural resources and agricultural industries	✔		Remains an important action and contributes to adaptive capacity	n/a
Objective 1.3: Maximise biodiversity benefits of sequestering carbon in the landscape and minimise adverse effects	✔		Contributes to both mitigation and adaptation	n/a
Objective 1.4: Protect and manage the visual character of the landscape	✔	✔	Essential in maintaining the social-ecological connection but will become increasingly difficult under climate change Agencies will need to work with communities to define and prioritise social and ecological 'hot spots' in order to plan for future management that maintains social and ecological values in the face of change The objective remains relevant under the timeframe of the current RCS, although will require revision for the next RCS	Protect and manage the visual character of priority areas within the landscape

SECTION 4

MITIGATION

CARBON SEQUESTRATION

Carbon sequestration is the general term used for the capture and long-term storage of carbon dioxide (CO_2). Capture takes place at either the point of emission or through natural processes such as photosynthesis. Storage can occur though one of several processes; soil, plant, geological, ocean or mineral sequestration[120]. The total above-ground carbon stocks on Victoria's publicly managed land are estimated to be 750 Million tonne (Mt) (2750 Mt CO_2)[121]. Results from the 'Fullcam' carbon accounting model simulations suggest that harvesting, bushfires and prescribed burns are major causes of change in carbon stocks on Victoria's publicly managed land. Figures for carbon stocks on privately managed land in Victoria are not available.

The average amount of organic carbon in the top 30 cm of Australian soil is estimated to be 29.7 tonnes per hectare[122]. The largest soil organic carbon stores per hectare occur in the cool, temperate zones, which have above average rainfall and extensive eucalyptus forests and rainforests[123]. These forest types occur in parts of the Otway Ranges, the Central Highlands, East Gippsland and extensive areas of Tasmania. The amount of organic carbon in Australian agricultural soils varies significantly. For example peat soils under pasture where soil organic carbon content can be as high as 10%, to less than 1% for heavily cultivated soils[124].

Mitigation refers to avoiding emissions of carbon dioxide into the atmosphere. Decay or combustion of organic matter leads to carbon dioxide release and in most cases debate about emissions reduction centres on reducing use of fossil fuels. In an NRM context in the Glenelg Hopkins region, where large quantities of carbon are stored in soils and vegetation, mitigating the loss of these carbon stores is most important and will ensure that large quantities of carbon will not enter the atmosphere and further exacerbate climate change.

Many of Australia's low cost carbon sequestration and emissions abatement opportunities are within the forestry and agriculture sectors. ClimateWorks Australia identified possible emissions abatement of 50 Mt CO_2 through a combination of reforestation and agriculture practice change[125].

Practices such as commercial carbon plantings and environmental plantings were investigated and found to have the potential to significantly contribute to Australia's emissions abatement. Reforestation of less than 1.5% of Australia's agricultural land with environmental carbon plantings has an estimated emissions abatement potential of 45 Mt CO_2 per year.

Plantings within the agricultural landscape, through the establishment of windbreaks, riparian vegetation and shade trees, will play a meaningful role in carbon sequestration[126]. In addition to plantings, the implementation of other agricultural best practices will contribute to increased carbon sequestration as well as increasing resilience to climate change. Practices such as minimum till, nutrient management, increasing groundcover and improved pasture management all have the potential to improve soil health and increase carbon sequestration[127]. Improved pasture management implemented over 53 Million hectares (Mha) of Australia's farmland has an emission abatement potential of 3 Mt CO_2 per year. This could be achieved through implementing practices such as optimal grazing intensity and timing, increasing deep rooted perennials and optimal nutrient management. Although there are some uncertainties around the carbon sequestration ability of soils in Australia, agricultural emissions abatement and carbon sequestration activities are considered low risk as they provide co-benefits of soil health and productivity improvement[128].

EMISSIONS REDUCTION FUND

On 24 November 2014, an amended Carbon Farming Initiative Amendment Bill 2014 was passed by the Australian Parliament, establishing the Emissions Reduction Fund (ERF). Existing Carbon Farming Initiative projects were automatically transitioned to the Emissions Reduction Fund, with changes to current and new methods not affecting existing projects. Methods approved under the ERF consist of a range of different types of projects. They must achieve a reduction in emissions and meet all eligibility criteria under the ERF.

Existing projects were provided with the option to continue to use the version of the method in force when their project was approved, or to apply to use another applicable Emissions Reduction Fund method. Under the Emissions Reduction Fund, vegetation-related carbon sequestration methods fall under four general categories:

- avoided clearing of native regrowth
- avoided land clearing
- designated verified carbon standard projects
- savannah fire management.

The Australian Government Department of the Environment has published a set of method development guidelines. These guidelines are designed to help stakeholders and technical working groups with the development of methods. They also assist to understand what is considered when methodology determinations are assessed by the Emissions Reduction Assurance Committee[129].

An effective emissions reductions fund has the potential to contribute to climate change mitigation through encouraging practices that sequester carbon, improve soil health and resilience, while potentially improving ecosystem resilience across agricultural landscapes.

Soil Carbon Sequestration and Mitigating Soil Carbon Loss

The bulk of carbon entering soil is in the form of plant residues such as leaves and roots. Any practice that enhances productivity and the return of plant residues to the soil is likely to lead to an increase in soil carbon, although increases may be short-lived, or difficult to detect for many years. Plant residue inputs are influenced by a number of inter-related factors including the type of plants being grown, amount of dry matter the plants accumulate over the growing season and environmental factors which govern plant production. Any change in land management leading to increased carbon in soil or vegetation must be continued indefinitely to maintain the increased stock of soil organic carbon[130].

A variety of management practices can slow the rate of soil carbon loss or increase soil carbon levels by increasing inputs. Fire can also lead to an increase in soil carbon by converting organic matter into charcoal. However, fire also leads to carbon losses through the process of combustion.

Within existing agricultural systems, the greatest theoretical potential for soil carbon sequestration is from large additions of organic materials, such as manure and green waste, maximising pasture phases in mixed cropping systems and shifting from annual to perennial species in permanent pastures[131]. The greatest gains may be made from more radical management shifts such as conversion from cropping to permanent pasture, and retirement and restoration of degraded land. Many of the management options that attempt to increase soil organic carbon also improve overall farm productivity and are already being adopted in various regions of Australia (for example, controlled traffic farming). However, ERF-approved practices that increase soil carbon could significantly increase nitrogen-based greenhouse gas emissions in some regions of Australia[132].

The Victorian parliamentary inquiry into soil carbon sequestration recognised the various agricultural and environmental benefits associated with soil carbon sequestration. These included improved soil health, agricultural productivity, biodiversity and water quality outcomes. The Committee also identified considerable risks and challenges associated with the measurement of soil carbon and participating in carbon trading. It was noted that some soil carbon sequestration practices may have adverse agricultural impacts, such as loss of agricultural land and questionable economic benefits[133].

Carbon Sequestration and Mitigating Carbon Loss Through Afforestation, Revegetation and Vegetation Management

Carbon sequestration through vegetation in Australia was defined through the ERF as the net amount of carbon that is stored in live vegetative components (leaves and roots) and that could be potentially claimed for carbon credits. Under the ERF methodology determination, abatement is calculated as the change in the amount of carbon stored in a project area (through growth of trees, natural decay and disturbance events such as fire, pests, disease and storms), minus emissions resulting from fire and from fuel used to establish and maintain the project.

Converting agricultural land to woody vegetation will remove carbon from atmospheric carbon dioxide and contribute to climate change mitigation. However, it may also have negative indirect land use change impacts.

Establishing new forests, grass or perennial shrubs, including perennial biofuel crops if they can be successfully grown on degraded land or land of limited agricultural value, are considered good options for implementing a carbon sequestration program. Such areas would potentially have minimal impact on food production and avoid the negative indirect impacts of land use change. Such areas would include:

- polluted soils affected by past industrial activity
- salt-affected soils
- steep land with a large erosion and landslip risk
- land that has become degraded for various reasons, excluding areas with biodiverse remnants.

CSIRO studies suggest that a carbon price ranging from between $18 - $40 t CO_2/year is likely to be needed for carbon farming to be profitable in Australia under most plausible scenarios. Lower price (~$18/t) is relevant to 3–4 row farm forestry belts established on areas of lowest productivity on farms in higher rainfall areas. There are few areas economically viable for carbon-farming-only focused schemes. Co-benefits of revegetation such as enhanced biodiversity, connectivity and erosion control need to be considered in any incentive scheme design and supplementary payments may be needed to make biodiverse environmental plantings competitive with other land uses[134]. The negative aspects of carbon farming include the potential for monoculture plantations to be established replacing biodiverse remnants, and unintended off-site impacts such as reduced water runoff and yield.

BLUE CARBON

Carbon Sequestration and Mitigating Carbon Loss from Aquatic Habitats

Saltmarsh, mangroves, and seagrass meadows are collectively known as vegetated coastal habitats or blue carbon habitats. Blue carbon habitats are reported to store organic carbon at almost 40 times the rate of terrestrial systems[135]. The relatively anaerobic soils of vegetated coastal habitats prevent organic carbon remineralisation and tend to promote long-term sequestration[136 137]. Carbon may be stored for centuries to millennia and never become saturated due to the vertical accretion of sediment. Vegetated coastal habitats both produce and store their own carbon as well as trapping carbon produced from other locations. The ability to trap particles and suspended sediment means that vegetated coastal habitats may appropriate large quantities of the organic carbon that originates from adjacent habitats, both terrestrial and marine[138 139 140 141].

The degradation and loss of vegetated coastal habitats via mismanagement could shift them from carbon sinks to carbon sources, causing them to release atmospheric carbon dioxide[142]. While natural disturbance events can lead to the loss of stored organic carbon, anthropogenic impacts including clearing of land, land fill, tidal restriction, stock grazing, and degradation of water quality have consistently driven more severe losses[143]. The current global estimates of saltmarsh and mangrove habitat loss are around 25–35%[144 145 146].

Blue Carbon in the Glenelg Hopkins Region

A recent Deakin University report, commissioned by Glenelg Hopkins CMA, estimated that the region has significant blue carbon stocks[147]. Both the saltmarshes and wetlands of the Glenelg Hopkins region have high carbon values, with exceptionally high values recorded within saltmarsh communities at Warrnambool.

Some of the other high-carbon stock sites sampled occur within areas where there have been large sections of saltmarsh cleared for agriculture, housing, or recreation such as Yambuk, Port Fairy and Warrnambool.

Across the sample sites in the Glenelg Hopkins region, areas higher in the estuaries (or closer to fluvial inputs) were associated with higher carbon stocks. Although the carbon stocks in saltmarshes and estuaries are significant, carbon in freshwater wetlands is even higher. Wetlands comprise 98% of the blue carbon stocks in the Glenelg Hopkins region. This is due to their extensive distribution (almost 7,300 hectares across the region) as well as their high carbon stock per unit area.

The trends identified in blue carbon stocks throughout the region provide a valuable insight for identifying appropriate locations for revegetation (and potentially carbon offset) programs. The protection and improvement of these habitats is a high priority for both adaptation and mitigation in response to climate change.

Further assessments are currently being undertaken by Deakin University to determine carbon stocks in freshwater wetlands across Victoria.

Restoring and/or protecting coastal and inland wetlands from degradation can potentially:

- stop drainage-induced releases of carbon and reactivate carbon sequestration
- be a more economically viable way to store carbon (via protection and restoration of aquatic ecosystems) than the alternative of terrestrial carbon storage
- enhance industries such as fisheries and tourism
- enhance water quality, flood and storm surge mitigation.

REVEGETATION

There is no set of mitigation or sequestration practices that are universally applicable and effective in reducing greenhouse gas emissions. Practices need to be evaluated for each landscape and for individual systems, taking into account climate, social setting, historical patterns of land use and management, as well as potential to create negative impacts. Carbon planting projects, if not implemented carefully, could have negative impacts such as increased land clearing or decreased biodiversity.

A number of questions should be asked before deciding whether a carbon planting project should be encouraged or discouraged in the Glenelg Hopkins region. This includes questions regarding opportunities for increased connectivity as well as protecting areas of high agricultural productivity. It is also important that community values are considered including potential risks such as fire and hydrological influences.

Community consultation has identified a number of priorities and concerns regarding carbon planting projects, which are summarised in Table 11. These community-identified priorities link very closely with a number of the priorities for asset adaptation contained within Section 3 - Adaptation. Community concerns are addressed in the following sections.

Table 11: Community priorities and concerns regarding carbon planting projects

Community Identified Priorities:	Community Identified Concerns:
Replacing and creating additional shelterbelts of native species to improve productivity and connectivity throughout the agricultural landscape Protecting existing red gums and allowing the regeneration of river red gums on farms River and stream revegetation projects to improve connectivity and water quality Improved support for existing biolink projects (for example Habitat 141, Grampians to Pyrenees and Basalt to Bay) to improve connectivity across the landscape	Potential impacts on hydrology Protection and reservation of productive agricultural land Changes to the landscape and the ecology due to the planting of single species and/or non-indigenous plantations Inappropriate planting of trees and shrubs in native grassland regions

BENEFITS AND RISKS

Revegetation and vegetation management are critical tools in climate change adaptation and mitigation. Vegetation communities provide essential services in the form of:

- **hydrology** – by filtering and managing runoff, ground water recharge and flood mitigation
- **ecology** – for maintaining and improving wildlife habitat, landscape connectivity and microclimate
- **agriculture** – for assisting in soil management, integrated pest management, improving microclimate and ecosystem services as well as diversifying income through farm forestry/carbon
- **adaptation** – facilitating climate change adaptation and building adaptive capacity through improved biodiversity values and connectivity
- **mitigation** – of greenhouse gas emissions through the sequestration of carbon.

Revegetation is a crucial component of both climate change adaptation and mitigation. However, there are risks associated with increases in vegetation, including altered hydrology and fire risks, which are described below.

Altered Hydrology

Revegetation can have a significant impact on local hydrology, particularly with an increase in woody vegetation. Trees generally use more water than smaller plants and therefore the establishment of tree species in what was formerly grassland is particularly likely to alter hydrology[148]. Plantation establishment has been documented to increase rainfall interception and transpiration, resulting in a decline in soil moisture and decreases in stream discharge[149].

Plantations within the Glenelg Hopkins region without access to groundwater tend to use all available rainfall, whereas those that have access to groundwater can cause a draw-down effect under the plantation itself which may extend beyond the edges of the plantation[150]. Effects on water yield will be most evident at a sub-catchment and local level. As a general rule, for each additional 10% of a sub-catchment covered by woody vegetation, potential water yield is predicted to fall by approximately 20 mm per year[151].

There are currently no controls for land use identified within the Victorian water allocation framework. This may change as a result of future reviews of the framework.

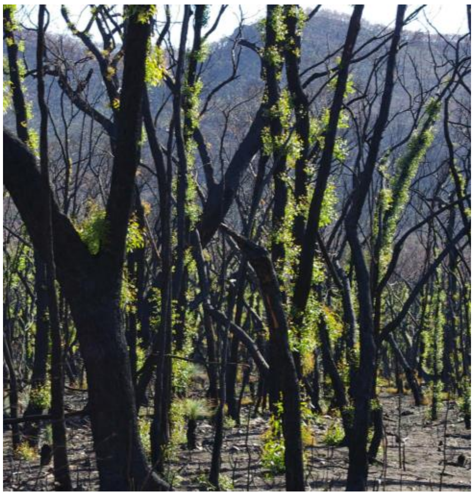
When considering the potential impacts of revegetation projects within the Glenelg Hopkins region, there are a range of factors that need to be taken into account. For example, in addition to carbon sequestration, there are multiple environmental co-benefits and ecosystem services associated with revegetation[152].

The potential negative effects of large revegetation projects can be managed through addressing the following factors:

- ensuring woody revegetation projects are not undertaken in native grasslands
- locating plantings in areas of greatest environmental co-benefit
- selecting locations where there would be little impact on consumptive water users and environmental flows[153]. The Western Region Sustainable Water Strategy identifies priority areas for consideration of water impacts of land use change.

Fire

The impact of increased fire risk comes not only from the direct impact of fire itself, but also the impact of fire management and suppression activities. More-frequent and large scale fuel reduction burning programs are the predictable response to increasing fire risk. This increase in frequency of burning can have devastating effects on vegetation communities, driving changes in floristic composition and structures, as well as favouring species that respond well to fire, including many weed species and species that are highly flammable. These changes to vegetation can in turn increase fire risk and hazards over the long term[154].



The potential for increased fire risk from carbon plantings can be managed through a variety of approaches. Private landholders should discuss these issues with the CMA, CFA and/or other land management agencies for advice on appropriate fire planning and risk mitigation. Within the public estate, consultation should occur between government agencies to ensure consideration in strategic fire planning.

In making decisions regarding fire risk, additional questions may need to be asked in relation to the location of the site within areas subject to a Bushfire Management Overlay, or other high risk fire management areas such as those identified in municipal fire management plans or similar.

PRIORITY LANDSCAPES FOR CLIMATE CHANGE MITIGATION

In order to prioritise landscapes for carbon planting and protection of existing vegetation, opportunities have been identified to maximise environmental benefits and minimise negative effects. Many of these benefits are described in the adaptation section of this document and include building landscape resilience through biodiverse revegetation and increasing connectivity throughout the landscape.

Both the environmental benefits and potential risks associated with carbon planting projects need to be taken into account. The key components in prioritising carbon planting in the region are terrestrial vegetation (green carbon) protection and enhancement, and wetland (blue carbon) protection and enhancement. The most appropriate locations in the region for these two carbon sequestering activities have been modelled by considering biodiversity value, carbon sequestration potential and agricultural production potential. The use of these datasets has enabled priority areas to be identified which aim to maximise biodiversity value and carbon sequestration while minimising impacts on areas with high agricultural production potential. Large scale carbon planting projects are less suitable in areas considered to have high agricultural production potential. However projects that have co-benefits for biodiversity, carbon sequestration and agricultural production would be highly encouraged within this area as well as across the entire region. Such projects would include wetland protection and enhancement, the creation of shelterbelts and the protection of paddock trees. Carbon plantings within the agricultural landscape should be complementary to sustainable agricultural production[155].

The management approaches for areas most suitable for protection and enhancement are as follows:

- **Protection** – targets high value ecosystems deemed to be in good condition with high carbon sequestration potential. Typically this applies to areas where most ecosystem functions exist. Priority would be given for minimal intervention through activities such as fencing, exclusion of stock, and pest plant and animal maintenance treatments.
- **Enhancement** – targets high value ecosystems deemed to be in poor condition with high carbon sequestration potential. Typically this applies to areas where many ecosystem functions are absent. Priority would be given for moderate intervention through activities such as revegetation, fencing, stock exclusion, and initial pest plant and animal treatment

A. Terrestrial Vegetation Protection and Enhancement

The protection of high value remnant vegetation for biodiversity and carbon outcomes facilitates the maintenance of an ecosystem's existing carbon cycle. Protecting priority areas prevents the release of existing carbon stores and promotes continued sequestration. The enhancement of degraded remnant vegetation for biodiversity and carbon outcomes increases ecosystem functionality and increases the carbon sequestration and storage ability. Vegetation enhancement can restore the carbon cycle and ultimately increase an ecosystem's carbon carrying capacity.

Terrestrial vegetation identified for protection includes existing high quality remnants on private land with high carbon sequestration potential and significant extent. The majority of land in public ownership, particularly parks and reserves, is already managed for protection and maintenance of ecosystem functions, and hence maintenance of their significant carbon reserves. In many cases the areas bordering public land are a priority for protection due to the connection with larger patches of vegetation. Ensuring the protection of existing high value and good condition terrestrial vegetation is critical for maintaining current carbon stores. Protecting the 124,000 ha of identified priority 'protection' areas has a estimated carbon sequestration potential of approximately 26.5 Mt/ha. These are shown in Figure 31.

Enhancement of terrestrial vegetation improves biodiversity and connectivity. Improving the quality of existing remnants not only increases resilience to climate change but also increases carbon sequestration. The areas identified for enhancement opportunities are usually smaller patches and are often impacted by threats such as pest plant and animals, erosion, over-grazing and clearing. Enhancement of the 308,000 ha of identified priority areas has a estimated carbon sequestration potential of approximately 26.2 Mt/ha.

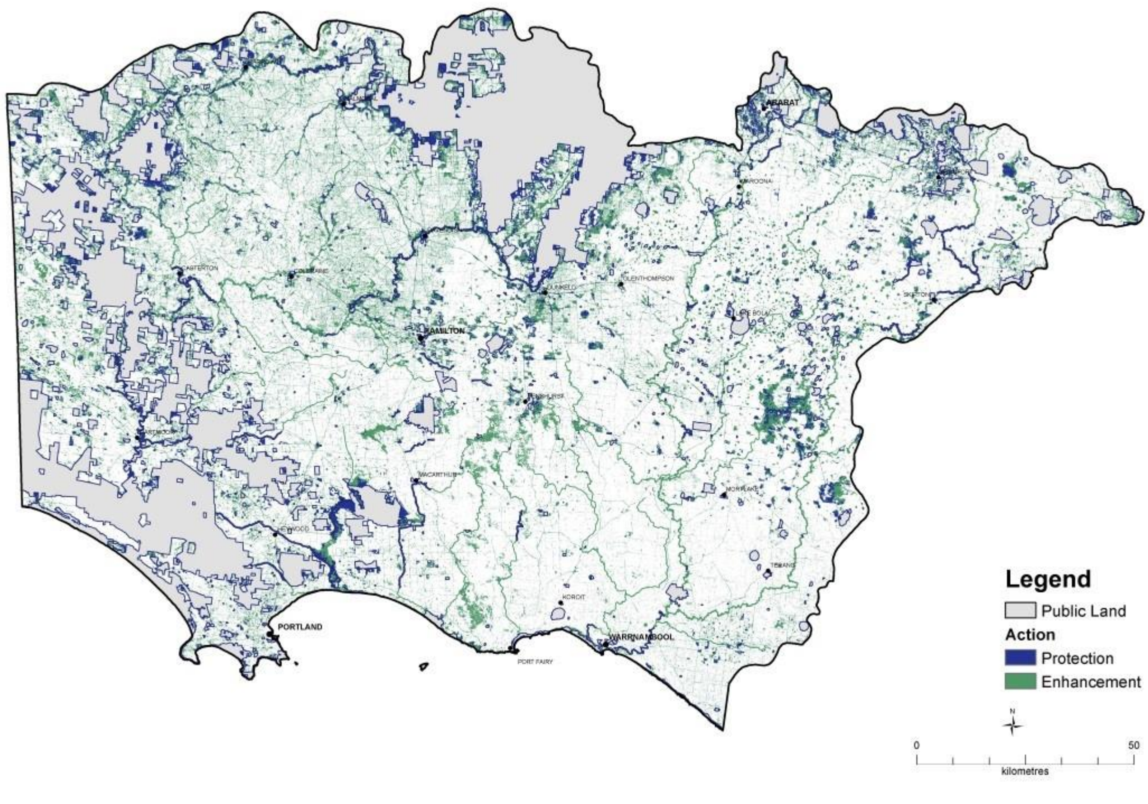


Figure 31: Terrestrial vegetation protection and enhancement

B. Wetland Protection and Enhancement

There is significant potential for the region's wetlands to act as carbon sinks. Wetlands are highly productive ecosystems within the landscape with carbon-rich organic sediments[156]. Despite their sequestration ability, if degraded, wetlands can become a significant source of emissions of carbon dioxide to the atmosphere. Around 1,280 million hectares of wetlands equating to 9% of the planet's surface is estimated to contain 35% of the global terrestrial carbon[157].

In order to further understand and prioritise wetland ecosystems, it is important to gain an understanding of the capacity of different wetlands types to sequester and store carbon. Similarly, it is important to understand the potential for a degraded wetland to be restored to a functioning state. Glenelg Hopkins CMA will prioritise further research on the region's wetlands, their current condition, location and carbon sequestration potential. It needs to be recognised that wetlands are more important as carbon stores than many other ecosystems, and protection efforts should be increased[158].

The Glenelg Hopkins region has more than 5,400 wetlands covering 73,000 ha or three percent of the catchment[159]. Estimates of their carbon sequestration potential highlight the significant role that the Glenelg Hopkins region can play in climate change mitigation. In developing the carbon sequestration estimates, rivers and waterway dependant ecosystems have been considered, in addition to wetands. These areas contribute to blue carbon sequestration. A conservative estimate of carbon in wetlands has been made based on limited research undertaken during the preparation of this strategy, is approximately 34.4 Mt. Protection of these wetlands is critical to prevent the loss of substantial amounts of carbon from the environment. Implementing enhancement activities will optimise carbon sequestration potential through re-establishing wetland function and reinstating the carbon cycle. Figure 32 highlights wetland areas for protection and enhancement.

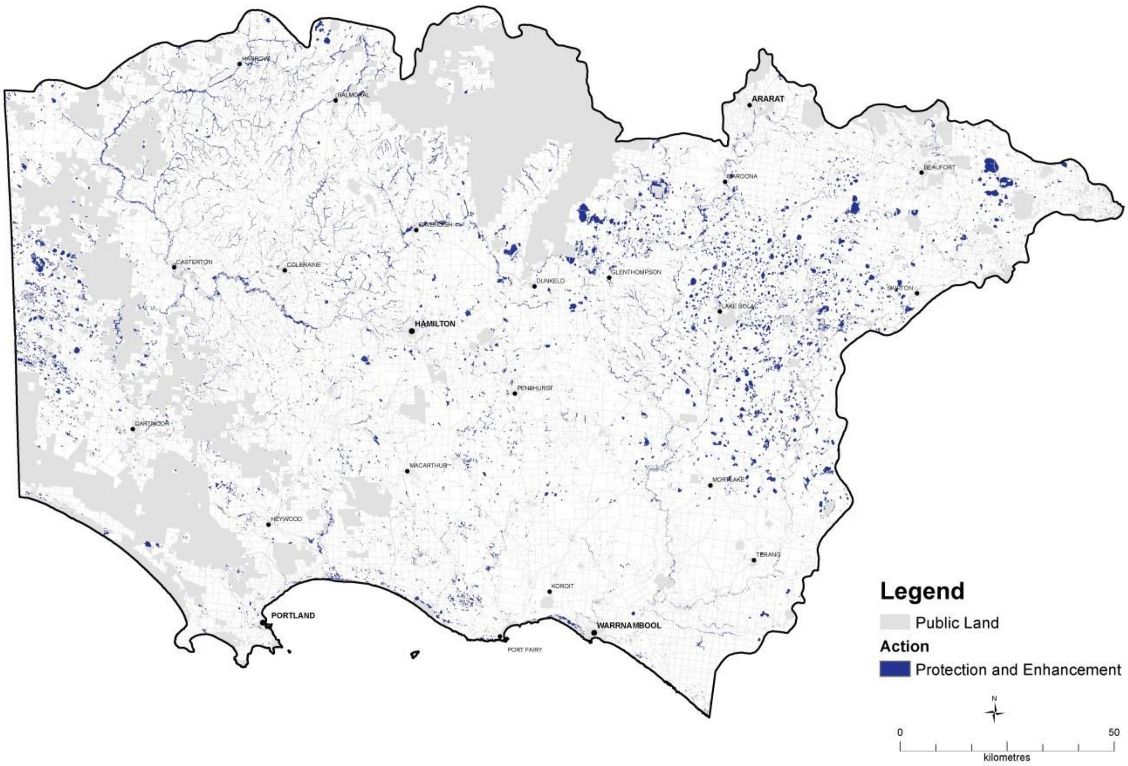


Figure 32: Wetlands for protection and enhancement

COMBINED PRIORITY LANDSCAPES FOR CLIMATE CHANGE MITIGATION ACTION

Prioritisation of landscapes for climate change mitigation action takes into account the protection, enhancement and carbon sequestration potential of both terrestrial vegetation and wetlands. Figure 33 shows the areas of dense or connecting high value ecosystems and high carbon sequestration potential.

The map highlights several priority areas including:

- the areas connecting the Glenelg River through Dergholm to the north of the catchment and east to the Grampians National Park and further east to the Pyrenees Ranges
- river systems and associated floodplains
- wetlands and wetland complexes
- coastal areas including estuaries and coastal saltmarsh habitats.

The areas not identified as priority landscapes are mostly agricultural areas and generally align with the Victorian Volcanic Plains. Projects that include wetland protection and enhancement as well as the creation of shelterbelts and the protection of paddock trees would be encouraged in these areas.

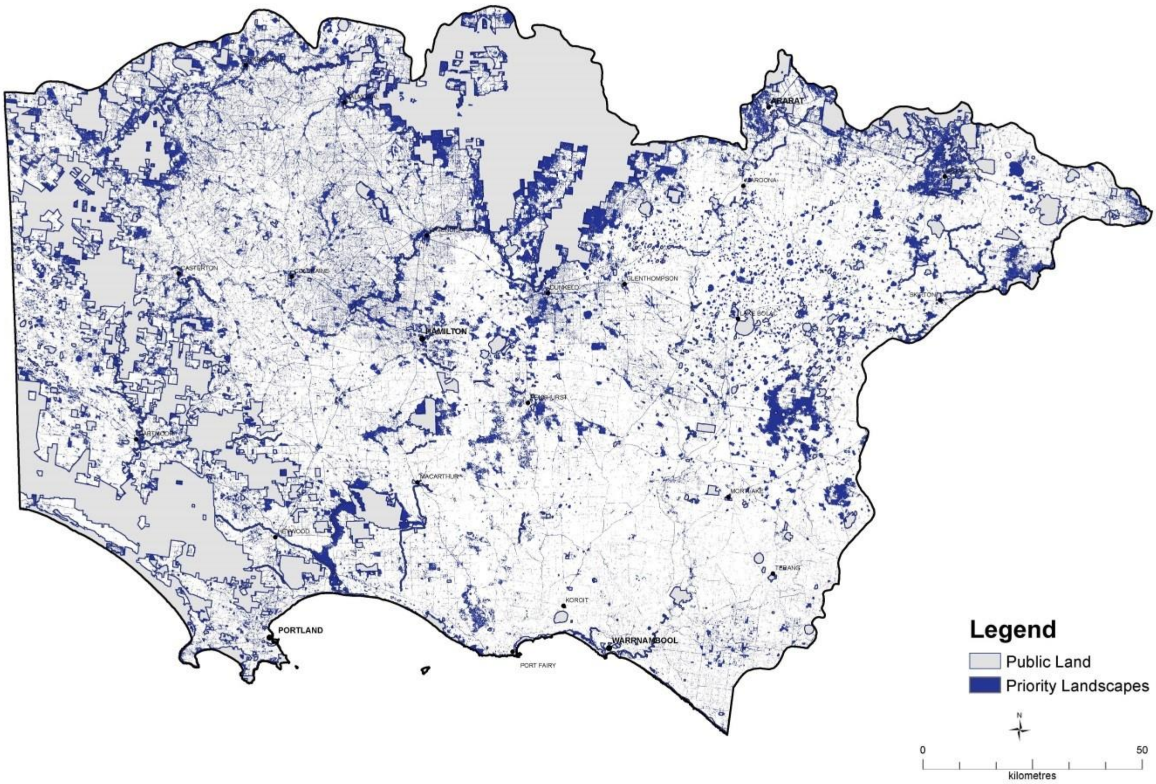


Figure 33: Priority landscapes for climate change mitigation action

SECTION 5

POLICY STATEMENTS AND STRATEGIC INITIATIVES

Using an approach which moves away from the development of static objectives to those that are more appropriate under a changing climate, Glenelg Hopkins CMA has developed a set of policy statements. These statements play an important role in ensuring the CMA adopts an adaptive approach to planning for the inherent uncertainty of a changing climate.

In alignment with the policy statements, strategic initiatives have been identified that promote the integration of climate change into the CMA's current and future practices and updates to the RCS. The initiatives within the strategy are designed to be reported on in alignment with the current RCS objectives and then integrated into the next RCS.

Implementation of initiatives will occur through current and future programs and projects, and be delivered at a range of spatial scales. Initiatives have been designed to be integrated into current practices, to reduce reliance on additional funding. Opportunities to secure additional funding will be pursued to support the expansion and broadening of initiative implementation. A logic map illustrated in Table 12 has been developed to illustrate the links between the strategic initiatives and the policy statements.

Policy Statements

The four policy statements and their components are listed below:

1. Provide regional leadership and set the example of best practice management of natural resources under climate change
    - Innovative solutions (on-ground work and business operations)
    - Share knowledge and inform stakeholders and the community
    - Encourage regional action and adaptation
    - Build and strengthen partnerships for adaptive management
    - Improve awareness of ecological values and ecosystem services
2. Manage for resilience and transformation
    - Conserve, protect and improve existing biological diversity
    - Accept and accommodate unavoidable loss and facilitate transformation, when possible
    - Address multiple threats simultaneously
    - Reduce pressure from sources other than climate change
    - Manage changes to species composition and allow space for species shifts
    - Manage and restore habitat and ecosystem function
    - Increase connectivity
3. Manage for multiple scenarios and for multiple possible futures
    - Implement adaptive pathways planning
    - Manage across landscapes and for long time-frames
4. Keep up-to-date with research and undertake long term monitoring of species, communities and ecological processes
    - Understand the interactions between social and ecological values under climate change
    - Monitor and manage species, communities, ecological processes and ecosystem services

Table 12: Glenelg Hopkins policy statements and strategic initiatives

	Strategic Initiatives	Policy Statements: Policy Statement 1 Provide regional leadership for the community & set the example of best practice management of natural resources under climate change	Policy Statement 2 Manage the Glenelg Hopkins region for resilience & transformation	Policy Statement 3 Implement adaptive management for multiple scenarios & for multiple possible futures	Policy Statement 4 Keep up to date with research & undertake long-term monitoring of species, communities & ecological processes
Community Participation	Support community participation in NRM activities & decision making	✔			
	Increase community awareness of ecosystem processes, climate change & the importance of protecting & improving biodiversity & landscape connectivity	✔			
	Integrate best available climate change information & data into regional planning				✔
	Integrate a pathways planning approach into project & strategy development where appropriate			✔	✔
Rivers & Floodplains	Protect existing high value waterways, & waterway dependent species & communities through managing existing threats		✔		
	Identify key indicator variables & resilience thresholds for climate change impacts on waterways, monitor change in waterway environments & revise management objectives in the Regional Waterway Strategy			✔	✔
	Monitor land use change & its relation to runoff & catchment hydrology				✔
	Periodically review rainfall & river in-flow changes, to inform water allocation & flood planning			✔	
	Identify drought refuge areas & prepare plans for their protection		✔		✔
	Encourage community participation in waterway health monitoring to facilitate improved information quality & involvement in the revision of management objectives & priorities	✔			
	Contribute to the periodic review of water resource availability & ensure reallocation protects waterway health			✔	
	Support the development of waterway & floodplain protection overlays & planning guidelines		✔		
Wetlands	Increase wetland protection & restoration based on their value to both biodiversity & carbon sequestration		✔		
	Further investigate the carbon storage & sequestration potential of wetlands				✔
	Contribute to the development of a carbon sequestration or emission abatement methodology for wetland protection & restoration to provide additional financial incentives for landholder management			✔	
	Monitor rainfall & wetland hydrology under climate change & establish thresholds for resilience				✔
	Monitor land use change & its impacts on wetland hydrology				✔
	Pursue the development of a wetland protection overlay & planning guidelines		✔		✔
Coasts & Estuaries	Support research on the fate of carbon in saltmarsh habitat subject to erosion				✔
	Increase coastal & estuarine protection & restoration based on their value to both biodiversity & carbon sequestration		✔		
	Further investigate the carbon storage & sequestration potential of coastal systems & the best means of long-term protection				✔
	Support community monitoring of coastal form & change over time	✔			
	Identify & monitor key indicators of coastal climate change impacts				✔
	Periodically review objectives in the Regional Waterway Strategy & Estuary Management plans to incorporate climate change factors			✔	✔
	Investigate the impact of climate change on the frequency & duration of Estuary closures				✔
	Monitor land use change & its impacts on coastal & estuarine systems				✔
	Monitor changes in rainfall patterns & sea level rise to inform the revision of flood models & integration of information into planning schemes			✔	✔
	Support the development of fine scale modelling of climate change impacts & sea level rise on coastal & estuarine systems				✔

	Strategic Initiatives	Policy Statements			
		Policy Statement 1 Provide regional leadership for the community & set the example of best practice management of natural resources under climate change	**Policy Statement 2** Manage the Glenelg Hopkins region for resilience & transformation	**Policy Statement 3** Implement adaptive management for multiple scenarios & for multiple possible futures	**Policy Statement 4** Keep up to date with research & undertake long-term monitoring of species, communities & ecological processes
Marine	Pursue monitoring of freshwater flows into marine & estuarine environments & the impacts of reductions		✔		
Marine	Support & implement actions that reduce catchment-based impacts on the marine environment		✔		
Marine	Promote the reduction of sediment reaching the marine environment		✔		
Marine	Promote the sustainable use of chemicals within the catchment to reduce the impacts on the marine environment		✔		
Terrestrial Habitat	Protect existing high value habitat through managing existing threats		✔		
Terrestrial Habitat	Build connectivity through the establishment of biolinks & corridors in priority areas		✔	✔	
Terrestrial Habitat	Support the establishment of biodiverse carbon plantings with multiple environmental benefits		✔	✔	
Terrestrial Habitat	Revise current revegetation species planting policies to incorporate climate change considerations			✔	✔
Terrestrial Habitat	Support the identification of fire refuge areas			✔	✔
Terrestrial Habitat	Implement habitat protection & enhancement programs through partnerships with landholders, Landcare & the community	✔	✔		
Species Populations & Communities	Support landscape scale revegetation & restoration programs to increase resilience & adaptive capacity		✔		
Species Populations & Communities	Adopt a planning & prioritisation process that focuses on maintaining function, functional redundancies & genetic diversity			✔	✔
Species Populations & Communities	Improve habitat quality, diversity & connectivity		✔		
Species Populations & Communities	Implement revegetation that buffers current remnant vegetation		✔		
Species Populations & Communities	Support research into the responses of species & communities to climate change				✔
Soil & Land	Monitor land use change				✔
Soil & Land	Support practices that increase groundcover		✔	✔	
Soil & Land	Promote an increase in pasture, crop & native plant diversity		✔	✔	
Soil & Land	Support the adoption of sustainable nutrient & pesticide management		✔		
Soil & Land	Support minimum & zero till cropping practices		✔		
Soil & Land	Support research into emerging soil carbon capture and storage methods				✔

MONITORING, EVALUATION AND REPORTING

The Monitoring, Evaluation and Reporting (MER) framework for this strategy will be incorporated into to current monitoring and evaluation plan for the RCS, which involves a series of key evaluation questions. These key evaluation questions form the basis for assessing implementation and its effectiveness and are divided in to the following categories: impact, appropriateness, effectiveness, efficiencies and legacy, as outlined in Table 13. Table 12 details the policy statements and associated strategic initiatives by asset. The strategic initiatives were informed by the adaptation pathways from each asset.

Table 13: Key evaluation questions

Category	Key Evaluation Question
Impact	In what ways and to what extent has the climate change strategy contributed to changing management practices? What increase has there been in the number of land managers applying best management practices?
	What is the status and trend in asset condition in the region?
	What progress has been made towards achieving the 20-year objectives?
Appropriateness	Do the management measures and actions remain the best management practices available or are there more appropriate methods that should be implemented?
Effectiveness	How effective were the implemented measures at meeting the objectives?
	Are the current management measures and actions still the most effective for meeting the 20-year objectives or are there other, more effective ways?
Efficiency	To what extent were the strategy implementation actions completed?
	To what extent have the program of measures been implemented?
Legacy	How are the effects of the climate change strategy expected to continue over time, particularly after the strategy has reached the end of its cycle?

Appendix 1

The information below provides further detail about the climate information used in developing the strategy.

Climate scenarios

Climate scenarios considered in this project in terms of carbon emission projections, based on the CMIP5 climate model results provided by CSIRO, were:

- RCP 4.5 – moderate scenario (in terms of future carbon emissions)
- RCP 8.5 – extreme scenario (in terms of future carbon emissions).

The two climate scenarios were chosen due to their representation of the two most likely pathways; RCP4.5 represents a pathway with moderate emissions that peak and then decline, with carbon dioxide concentration stabilising at about 540 ppm by the end of the twenty-first century, and RCP8.5 represents a high-emission scenario, for which carbon dioxide concentration reaches about 940 ppm by the end of the twenty-first century[160].

Direct climate stressors

The direct climate stressors provided in the CSIRO data used in this project were:

- mean Daily Maximum Temperatures (Tmax) for each season
- mean Daily Rainfall (precipitation) for each season.

These direct climate stressors were considered in relation to their relative importance on each of the natural asset types identified.

Climate change time frames

The baseline climate data for the CMIP5 climate projections is based on average climate variables for the period 1986–2005. For the purposes of this project the baseline year was identified as 1990. Hence, the 2090 time period was viewed to represent the 100=year timeframe scenario.

The years in which potential impacts were assessed in this project (based on RCP 4.5, moderate, and RCP 8.5, extreme, emission scenario information provided in the CMIP5 climate model results from CSIRO) were:

- 2030 (40 years from the baseline year)
- 2050 (60 years from the baseline year)
- 2070 (80 years from the baseline year)
- 2090 (100 years from the baseline year).

Climate related events

Bushfire and intense weather events

While climate change will have an impact on indirect climate stressors such as bushfire frequency and intensity, neither specific data nor surrogate information related to these events was available for use in this project.

Similarly the increased frequency of extreme events, while very important in relation to natural assets, was viewed as too difficult to represent in the current modelling.

However, it was felt by the project team that direct climate stressors relating to seasonal rainfall and maximum temperatures were a good indicator of the likely increased frequency of climate related events such as bushfire frequency and intensity. These same stressors were viewed as important when determining the likely impact of indirect climate change stressors relating to intense storm events on soils and land. It was felt that the likely impact of such events which involve intense wind and rainfall on soils and land assets were the health of ground or vegetation cover.

Sea level rise and storm surge

Anticipated sea level rise (SLR) and storm surge (SS) information is available for four time periods: 2009, 2040, 2070 and 2100. As these time frames do not match the time frames for emissions scenarios, a conservative approach was applied. This resulted in the SLR and SS information for 2040 being used for the 2030 climate scenario, the 2070 information being used for the 2050 and 2070 scenarios, and the 2100 information being used for the 2090 scenario, as shown in Table 14.

Table 14: Sea level rise data comparison

Year for which Anticipated sea level rise (SLR) & storm surge (SS) information is available	Years for which potential climate change impacts were assessed
2040	2030
2070	2050
2070	2070
2100	2090

Appendix 2

The vulnerability of assets has been determined through a process of assessing the exposure, sensitivity and adaptive capacity of natural assets. A detailed description of the inputs and criteria considered in the development of the vulnerability modelling for each asset is provided below.

Rivers

Exposure

Table 15 outlines the inputs for the exposure of rivers for vulnerability mapping.

Table 15: Inputs for the exposure of rivers for vulnerability mapping

Climate Stressors	Sensitivity inputs	Adaptive Capacity inputs
Mar to Nov – rainfall Nov to April – daily max temp	Regulated or not Perennial /permanent Terrain category – plains, intermediate, upper	% native veg presence within 100 m Quality of native veg within 100 m AVIRA – reduction in high flow mag, increase in probability of low flow, AVIRA – change in monthly flow variability

Sensitivity

The sensitivity of rivers was considered to depend primarily on the condition of riparian vegetation, instream habitat and water quality. Table 16 below outlines the specific inputs for the sensitivity of rivers for vulnerability mapping.

Table 16: Inputs for the sensitivity of rivers for vulnerability mapping

Indicator number	Sensitivity	1	2	3	4	5
1	Streamside zone – condition and intactness	No change to habitat quality and connectivity	Habitat quality suffers minor degradation but key ecological processes remain intact	Significant loss of habitat quality and connectivity but ecological processes remain largely intact	Major loss of habitat quality and increased fragmentation with long-term effects	Irretrievable loss of streamside zone extent
2	Instream habitat	Instream habitat remains in near pristine condition	Minor alteration to quality and composition of instream habitat, natural repair processes intact	Moderate alteration to habitat quality and composition, with some long-term effects	Instream habitat substantially degraded	Irreversible damage to instream habitat values
3	Ecosystem water quality	No discernible human impact	Minor damage to water dependent ecosystems, where full recovery could be expected	Moderate damage to water dependent ecosystems, where recovery would have minor long-term effects	Major damage to water dependent ecosystems, where recovery would have significant long-term effects	Irreversible damage to water dependent ecosystems

Adaptive capacity

Aquatic Value Identification and Risk Assessment (AVIRA) data relating to the hydrological properties of a watercourse was used to assign components of an adaptive capacity rating. Melbourne Water data was obtained to provide relevant information for watercourses within the Port Philip and Westernport CMA area. Table 17 outlines the inputs for the adaptive capacity of rivers for vulnerability mapping.

Table 17: Inputs for the adaptive capacity of rivers for vulnerability mapping

Criteria for consideration in assigning adaptive capacity			
% native vegetation within 100 metres	Quality of native vegetation within 100 metres	AVIRA catchment ratings for reduction in high flow magnitude, increase in proportion of low flow, change in monthly flow variability	Level of other threats (if known)

Wetlands

Exposure

Table 18 outlines the inputs for the exposure of wetlands for vulnerability mapping.

Table 18: Inputs for the exposure of wetlands for vulnerability mapping

Climate Stressors	Sensitivity inputs	Adaptive Capacity inputs
Mar to Nov – rainfall Nov to April - daily max temp	• Wetland type (FW meadows, marshes etc.) • Water source (river, groundwater) • Alpine/non-alpine • Within 2100 SLR and storm surge extent	• % native vegetation presence within 100 m • Dominant native vegetation quality within 100 m • Dominant land use within 100 m • Presence of drain, levee or cropping

Sensitivity

Table 19 below outlines the inputs for the sensitivity of wetlands for vulnerability mapping.

Table 19: Inputs for the sensitivity of wetlands for vulnerability mapping

Indicator number	Sensitivity	1	2	3	4	5
1	Hydrological processes	Processes unaffected	Minor and short-term loss of hydrological function	Significant but recoverable loss of hydrological function	Major loss of hydrological function	Irretrievable loss of hydrological function
2	Catchment and buffer integrity	Nil/minimal impact	Minor damage to contributing catchment and buffer	Moderate damage to catchment/buffer with some long-term impacts	Major alteration to catchment and buffer with long-term effects	Irreversible damage to catchment and buffer integrity
3	Biodiversity	Nil/minimal loss of ecosystem components and species	Loss of some ecosystem elements and/or species but repair and recolonisation within short timeframe	Some ecosystem components and species lost	Significant damage to key ecosystem components and long-term loss of species	Irretrievable loss of key ecosystem components and species

Adaptive capacity

Table 20 outlines the inputs for the adaptive capacity of wetlands for vulnerability mapping.

Table 20: Inputs for the adaptive capacity of wetlands for vulnerability mapping

Criteria for consideration in assigning adaptive capacity			
% of native vegetation within 100 metres	Quality of dominant native vegetation within 100 metres	Dominant land use within 100 metres	Presence of a drain, levee or cropping within wetland

Coasts and Estuaries

Exposure

Table 21 outlines the inputs for the exposure of coasts and estuaries for vulnerability mapping.

Table 21: Inputs for the exposure of estuaries and coastal wetlands for vulnerability mapping

Asset Type	Climate Stressors	Sensitivity inputs	Adaptive Capacity inputs
Estuaries	Mar to Nov – rainfall, sea level rise & storm surge	• Open – permanent & intermittent • Regulated catchment or not • Mouth type – bay/coast	• % native vegetation within catchment • Quality of native vegetation within catchment • Population & population density within catchment
Coastal Wetlands includes tidal wetlands & wetlands within anticipated 2100 SLR & storm surge extent	Mar to Nov – rainfall, sea level rise & storm surge	• Wetland type (Freshwater meadows, marshes etc.) • Wetland regime – supratidal • Water source (river, groundwater) • Within 2100 SLR & storm surge extent	• % native veg presence within 100 m • Dominant native veg quality within 100 m • Dominant land use within 100 m • Presence of drain, levee or cropping

Sensitivity

Table 22 outlines the inputs for the sensitivity of coastal wetlands and estuaries for vulnerability mapping.

Table 22: Inputs for the sensitivity of coastal wetlands and estuaries for vulnerability mapping

Asset type	Indicator number	Sensitivity	1	2	3	4	5
Estuaries	1	Hydrological character	Pocesses unaffected hydrological function	Minor and short-term change	Moderate change recoverable in medium term	Major change but recoverable in the long term	Irretrievable loss of hydrological function
	2	Catchment and buffer integrity	Nil/minimal impact	Minor damage to contributing catchment and buffer	Moderate damage to catchment/buffer with some long-term impacts	Major alteration to catchment and buffer with long-term effects	Irreversible damage to catchment and buffer integrity
	3	Biodiversity	Nil/minimal loss of ecosystem components and species	Loss of some ecosystem elements and/or species but repair and recolonisation within short timeframe	Some ecosystem components and species lost	Significant damage to key ecosystem components and long-term loss of species	Irretrievable loss of key ecosystem components and species
Coastal Wetlands	1	Hydrological processes	Processes unaffected	Minor and short-term loss of hydrological function	Significant but recoverable loss of hydrological function	Major loss of hydrological function	Irretrievable loss of hydrological function
	2	Catchment and buffer integrity	Nil/minimal impact	Minor damage to contributing catchment and buffer	Moderate damage to catchment/buffer with some long-term impacts	Major alteration to catchment and buffer with long-term effects	Irreversible damage to catchment and buffer integrity
	3	Biodiversity	Nil/minimal loss of ecosystem components and species	Loss of some ecosystem elements and/or species but repair and recolonisation within short timeframe	Some ecosystem components and species lost	Significant damage to key ecosystem components and long-term loss of species	Irretrievable loss of key ecosystem components and species

Adaptive capacity

Table 23 outlines the inputs for the adaptive capacity of coastal wetlands and estuaries for vulnerability mapping.

Table 23: Inputs for the adaptive capacity of coastal wetlands and estuaries for vulnerability mapping

Asset type	Criteria for consideration in assigning adaptive capacity			
Coastal wetlands	% of native vegetation within 100 metres	Quality of dominant native vegetation within 100 metres	Dominant land use within 100 metres	Presence of a drain, levee or cropping within wetland
Estuaries	% tree cover within estuary catchment	Population and population density within catchment	AVIRA catchment ratings for reduction in high flow magnitude, increase in proportion of low flow, change in monthly flow variability	Level of other threats (if known)

Terrestrial habitat

Exposure

Table 24 outlines the inputs for the exposure of soils used in the vulnerability mapping.

Table 24: Inputs for the exposure of soils used in the vulnerability mapping

Climate Stressors	Sensitivity inputs	Adaptive Capacity inputs
Total Rainfall Nov to April – daily max temp	• EVC sub-groups	• Site condition • Landscape connectivity

Sensitivity

Climate change is likely to result in an increased occurrence of high intensity storm and wind events. These events will place significant pressure on soil and land assets, such that areas with poor land or vegetation cover are likely to experience significant wind and water erosion. Table 25 outlines the inputs for the sensitivity of soils used in the vulnerability mapping.

Table 25: Inputs for the sensitivity of soils used in the vulnerability mapping

	Sensitivity	1	2	3	4	5
Indicator No.	Indicator	Very low	Low	Moderate	High	Very high
1	Hydrological processes	Processes unaffected	Minor and short-term loss of hydrological function	Significant but recoverable loss of hydrological function	Major loss of hydrological function	Irretrievable loss of hydrological function
2	Change in soil structure /properties	Soil physico-chemical properties unaltered	Some alteration to physico-chemical properties but capability and productivity largely unaffected	Significant changes to soil structure and properties reducing productivity in the short to medium term	Major alteration of soil physico-chemical properties with long-term impact on productivity	Irreversible changes to soil structure/properties
3	Hazard – salinity, sodicity etc.	No change in area of affected land	Minor increase in extent of land affected but no off-site impacts	Significant increase in extent of land affected with some off-site impacts	Major increase in land affected with significant off-site impacts	Irreversible and catastrophic effects

Adaptive capacity

Consideration was given to whether land management practices could be used to assign an adaptive capacity rating. It was agreed that while areas of native vegetation could be assigned a greater adaptive capacity than cleared areas, there was no basis to differentiate the adaptive capacity of areas under agricultural land management.

It was viewed that land degradation impacts on the adaptive capacity of the soil and land asset, and hence spatial datasets that identify areas currently or recently subject to significant land degradation were reviewed. Table 26 outlines the inputs for the adaptive capacity of soils used in the vulnerability mapping.

Table 26: Inputs for the adaptive capacity of soils used in the vulnerability mapping

Criteria for consideration in assigning adaptive capacity		
Native vegetation cover	Level of degradation – salinity, erosion, acid sulfate soils where applicable	Groundcover

Soil salinity

No recent statewide spatial datasets were identified that depict areas currently impacted by soil salinity and soil erosion. To demonstrate the application of this information, a version of dryland salinity discharge mapping that was compiled in 2000 was used. This set of statewide datasets comprising line, point, and polygon features depicted the extent of dryland salt-affected soil mapped across the state of Victoria. Sites with a rating of medium or high severity were considered to be impacted by dryland salinity.

Soil erosion

Measures of soil erosion could not be used in the vulnerability mapping as suitable statewide dataset depicting areas subject to current soil erosion are not available.

Acid sulfate soils

Coastal acid sulfate soils were also identified to significantly impact on adaptive capacity. The spatial data representing Victorian coastal lands which have the potential to contain coastal acid sulfate soil was utilised for this purpose.

Soil and Land

Exposure

Table 27 outlines the inputs for the exposure of soils used in the vulnerability mapping.

Table 27: Inputs for the exposure of soils used in the vulnerability mapping

Climate Stressors	Sensitivity inputs	Adaptive Capacity inputs
Total Rainfall Nov to April - daily max temp	• EVC sub-groups	• Site condition • Landscape connectivity

Sensitivity

Climate change is likely to result in an increased occurrence of high intensity storm and wind events. These events will place significant pressure on soil and land assets, such that areas with poor land or vegetation cover are likely to experience significant wind and water erosion. Table 28 outlines the inputs for the sensitivity of soils used in the vulnerability mapping:

Table 28: Inputs for the sensitivity of soils used in the vulnerability mapping

	Sensitivity	1	2	3	4	5
Indicator No.	Indicator	Very low	Low	Moderate	High	Very high
1	Hydrological processes	Processes unaffected	Minor and short-term loss of hydrological function	Significant but recoverable loss of hydrological function	Major loss of hydrological function	Irretrievable loss of hydrological function
2	Change in soil structure /properties	Soil physico-chemical properties unaltered	Some alteration to physico-chemical properties but capability and productivity largely unaffected	Significant changes to soil structure and properties reducing productivity in the short to medium term	Major alteration of soil physico-chemical properties with long-term impact on productivity	Irreversible changes to soil structure/properties
3	Hazard - salinity, sodicity etc.	No change in area of affected land	Minor increase in extent of land affected but no off-site impacts	Significant increase in extent of land affected with some off-site impacts	Major increase in land affected with significant off-site impacts	Irreversible and catastrophic effects

Adaptive capacity

Consideration was given to whether land management practices could be used to assign an adaptive capacity rating. It was agreed that while areas of native vegetation could be assigned a greater adaptive capacity than cleared areas, there was no basis to differentiate the adaptive capacity of areas under agricultural land management.

It was viewed that land degradation impacts on the adaptive capacity of the soil and land asset, and hence spatial datasets that identify areas currently or recently subject to significant land degradation were reviewed. Table 29 outlines the inputs for the adaptive capacity of soils used in the vulnerability mapping.

Table 29: Inputs for the adaptive capacity of soils used in the vulnerability mapping

Criteria for consideration in assigning adaptive capacity		
Native vegetation cover	Level of degradation – salinity, erosion, acid sulfate soils where applicable	Groundcover

Soil salinity

No recent statewide spatial datasets were identified that depict areas currently impacted by soil salinity and soil erosion. To demonstrate the application of this information, a version of dryland salinity discharge mapping that was compiled in 2000 was used. This set of statewide datasets comprising line, point, and polygon features depicted the extent of dryland salt-affected soil mapped across the state of Victoria. Sites with a rating of medium or high severity were considered to be impacted by dryland salinity.

Soil erosion

Measures of soil erosion could not be used in the vulnerability mapping as suitable state-wide dataset depicting areas subject to current soil erosion are not available.

Acid sulfate soils

Coastal acid sulfate soils were also identified to significantly impact on adaptive capacity. The spatial data representing Victorian coastal lands which have the potential to contain coastal acid sulfate soil was utilised for this purpose.

Appendix 3

Table 30: Community participation - identification of potential adaptation actions, benefits, relevance over time, risks and contribution to the adaptation principles

	Contribution to resilience						Adaptation phase			Relevance over time					Potential for maladaptation or perverse outcomes				Adaptation Principles				
Action	Protection	Improved connectivity	Improved biodiversity	Increased knowledge	Monitoring	Supporting/improve function	Resilience	Transition	Transformation	2016	2018	2020	2025	2030	Negative impact on other species/systems	Path dependency/lock in trap	perverse outcomes	Exacerbates existing stressors	Leadership	Resilience & transformation	Adaptive Management	Research & Monitoring	Notes
Continue to support tender programs	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓					✓	✓	✓		Have proven success
Continue to support Landcare, Coastcare and Waterwatch	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓			✓				Contribute greatly to NRM and community connection, reliant on ongoing funding and paid facilitators
Community partnerships	✓	✓	✓	✓			✓	✓		✓	✓	✓	✓	✓					✓				Develop ongoing relationships
Community ecological monitoring programs		✓		✓		✓	✓	✓			✓	✓	✓	✓								✓	Citizen science programs contribute greatly to ecological knowledge as well as enhancing community connection to nature
Community involvement in decision making and project planning		✓		✓	✓	✓	✓		✓			✓	✓	✓			✓		✓	✓			Relies on communities being informed and connected to nature, risk of conflicting interests
Supporting and instigating social learning and transformational action		✓		✓	✓	✓	✓		✓				✓	✓			✓		✓	✓			Dependent on building strong and trusting relationship

Table 31: Rivers and floodplains - identification of potential adaptation actions, benefits, relevance over time, risks and contribution to the adaptation principles

	Contribution to resilience						Adaptation phase			Relevance over time					Potential for maladaptation or perverse outcomes				Adaptation Principles				
Action	Protection	Improved connectivity	Improved biodiversity	Increased knowledge	Monitoring	Supporting/improve function	Resilience	Transition	Transformation	2016	2018	2020	2025	2030	Negative impact on other species/systems	Path dependency/lock in trap	perverse outcomes	Exacerbates existing stressors	Leadership	Resilience & transformation	Adaptive Management	Research & Monitoring	Notes
Protect existing high quality habitat	✓					✓	✓			✓	✓	✓	✓	✓						✓			Existing threats must be dealt with to improve resilience
Reduce existing threats such as invasive species	✓		✓			✓	✓			✓	✓	✓								✓			Knowledge gaps regarding aquatic weed distribution and management
Protect upstream sources of woody debris & maintain diversity of stream structure	✓	✓	✓			✓	✓			✓	✓	✓	✓							✓			
Improve the resilience of identified drought refugia	✓	✓	✓			✓	✓			✓	✓	✓	✓	✓			✓			✓			These are also carp breeding areas and will require ongoing management
Ongoing monitoring of water quality fauna & flora				✓	✓		✓			✓	✓	✓	✓	✓								✓	
Improve connectivity – removal of barriers & increase in riparian vegetation		✓	✓				✓			✓	✓	✓	✓				✓			✓			This will also support the resilience of estuarine & marine & coastal systems Could increase carp extent & other pests
In stream planting & structures to stabilise habitats & riparian vegetation & buffer zones to shade & mitigate temperature increase		✓	✓			✓	✓			✓	✓	✓	✓							✓			Particularly important for protection from the impacts of heatwave
Community education focus on values, expectations & acceptance of change				✓				✓		✓	✓	✓	✓	✓					✓				Increasing knowledge will not be enough, education will need to shift towards increasing the 'value' of nature
Develop legislative framework the integration of water management & harvesting protocols	✓	✓				✓			✓			✓	✓						✓			✓	Legislative support essential in prioritising environmental flows appropriately
Education & prioritisation framework for maintaining environmental & cultural flows				✓		✓			✓	✓	✓	✓							✓		✓	✓	
Land acquisition & reinstatement of floodplains		✓					✓	✓	✓			✓	✓							✓			Possible changes to leasing conditions &/or land swaps
Reinstatement of traditional hydrological system		✓				✓	✓	✓	✓					✓	✓					✓			Reinstate traditional hydrological system Dams do provide refuge for some species

Table 32: Wetlands - identification of potential adaptation actions, benefits, relevance over time, risks and contribution to the adaptation principles

	Contribution to resilience						Adaptation phase			Relevance over time				Potential for maladaptation/perverse outcomes					Adaptation Principles				
Action	Protection	Improved connectivity	Improved biodiversity	Increased knowledge	Monitoring	Supporting/improve function	Resilience	Transition	Transformation	2020	2025	2030	2050	Increases emissions	Negative impact on other species/systems	Reduces incentives	Path dependency/lock in trap	Exacerbates existing stressors	Leadership	Resilience & transformation	Adaptive Management	Research & Monitoring	Notes
Reinstate hydrological processes	✓	✓	✓			✓		✓	✓	✓	✓	✓	✓							✓			Expectations of permanent water are inappropriate for ephemeral systems. If hydrology is not restored by 2050, a tipping point could be reached for northern wetlands resulting in permanent loss
Exclusion fencing	✓		✓	✓			✓			✓					✓			✓		✓			Removing grazing completely can reduce diversity & increase weeds, negatively impacting on native biodiversity.
Grazing management	✓		✓			✓	✓	✓		✓	✓	✓	✓		✓					✓			Done inexpertly, grazing will have negative impacts. It would be inappropriate to introduce grazing to systems not previously grazed
Weed control	✓		✓			✓	✓			✓	✓				✓		✓			✓			Improved identification of weed species in wetlands
Mapping & monitoring of wetlands	✓			✓	✓			✓		✓												✓	
Landowner education (land use change & expansion of cropping)				✓				✓	✓	✓	✓	✓	✓		✓	✓			✓				Program can be seen as threatening - causing isolation/resistance if not well implemented
Adding landscape connectivity within clusters – (vegetation corridors/shelter/cover/paddock trees)		✓				✓	✓				✓									✓			
Protection of groundwater dependent wetlands	✓		✓			✓					✓									✓			
Establish an economic value for wetlands				✓				✓		✓				✓		✓						✓	
Method of prioritising within & between clusters		✓		✓				✓		✓												✓	Prioritisation could result in triage & the permanent loss of low priority wetlands
Overlay & development of planning guidelines	✓	✓	✓	✓	✓			✓	✓	✓	✓								✓		✓		
Translocation of species	✓		✓			✓			✓				✓		✓					✓			Careful evaluation required in planning as species relocations may have negative impact on remaining species
Conservation zones: actively managing for conservation of wetlands & associated biodiversity	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓								✓	✓		

Table 33: Coast and estuaries - identification of potential adaptation actions, benefits, relevance over time, risks and contribution to the adaptation principles

	Contribution to resilience						Adaptation phase			Relevance over time					Potential for maladaptation or perverse outcomes				Adaptation Principles				
Action	Protection	Improve connectivity	Improved biodiversity	Increased knowledge	Monitoring	Supporting/improve function	Resilience	Transition	Transformation	2016	2018	2020	2025	2030	Negative impact on other species/systems	Path dependency/lock in trap	perverse outcomes	Exacerbates existing stressors	Leadership	Resilience & transformation	Adaptive Management	Research & Monitoring	Notes
Protect and restore coastal vegetation		✓	✓			✓	✓			✓										✓			Coastal vegetation is fundamental to the protection of system function and protection from storm surge
Community awareness raising				✓			✓			✓									✓				Coastal areas have a complicated range of social values that need to be understood
Managing land use pressure and grazing in coastal systems	✓	✓	✓			✓	✓			✓										✓	✓		
Coastal landholder incentives	✓	✓	✓			✓	✓			✓	✓								✓	✓			
Fine scale modelling of climate change impacts and sea level rise				✓				✓		✓	✓											✓	
Erosion monitoring				✓	✓			✓		✓	✓	✓	✓	✓								✓	
Reduce development pressure on costal systems	✓					✓	✓	✓		✓	✓	✓	✓	✓						✓			
Engage with community to raise the value of coastal systems for ecosystem services and the impacts of climate change				✓				✓		✓	✓	✓	✓	✓					✓		✓		In particular the value of seagrass and saltmarsh, which are not only an essential component of the ecosystem but also sequester significant amounts of CO_2
Investigate market-based options and joint ventures for the use of coastal systems for co-benefits				✓				✓		✓	✓	✓				✓	✓					✓	Research may provide new and innovative options
Coastal land acquisition	✓	✓						✓	✓		✓	✓	✓	✓	✓	✓				✓			Dependent upon appropriate resources for ongoing management
Influence state policy for changes to the planning scheme				✓				✓		✓	✓	✓	✓				✓		✓				
Develop planning tools which are flexible and allow for creativity and innovation in accommodating change and new research and technology				✓					✓				✓	✓	✓	✓	✓		✓		✓		

Table 34: Marine - identification of potential adaptation actions, benefits, relevance over time, risks and contribution to the adaptation principle

	Contribution to resilience						Adaptation phase			Relevance over time					Potential for maladaptation or perverse outcomes				Adaptation Principles				
Action	Protection	Improved connectivity	Improved biodiversity	Increased knowledge	Monitoring	Supporting/improve function	Resilience	Transition	Transformation	2016	2018	2020	2025	2030	Negative impact on other species/systems	Path dependency/lock in trap	perverse outcomes	Exacerbates existing stressors	Leadership	Resilience & transformation	Adaptive Management	Research & Monitoring	Notes
Community awareness raising				✓			✓	✓		✓	✓	✓	✓	✓					✓				Need a new approach focused on altering values and accepting change rather than information provision
Ensure adequate freshwater flows to support marine & estuarine values		✓				✓		✓	✓			✓	✓	✓	✓					✓			An added benefit to the actions suggested to improve resilience of estuaries and rivers
Maintaining connectivity between estuaries and marine systems		✓	✓			✓			✓			✓	✓	✓	✓					✓			In particular hydrological connectivity from rivers through estuaries into the marine environment is essential
Providing facilities for boat hygiene and wash down	✓							✓			✓									✓			This will also depend on behaviour change and an increase in the social value of the environment
Ballast water controls and restriction of boat movements to limit pest spread	✓							✓			✓	✓							✓				As above
Monitoring of marine pests					✓		✓			✓	✓	✓	✓	✓								✓	Will also help to identify changes to species distributions and abundances
Monitoring fish populations & adjusting allowable take accordingly			✓		✓		✓	✓	✓		✓	✓	✓						✓		✓		
Managing the flow of chemicals and sediment into marine systems from land	✓					✓	✓			✓	✓	✓								✓		✓	
Investigate the possibility of movable/floating infrastructure	✓						✓			✓	✓	✓							✓	✓	✓		To maintain access to marine resources infrastructure will be required to adapt to changing sea level and withstand storm surge

Table 35: Terrestrial habitat - identification of potential adaptation actions, benefits, relevance over time, risks and contribution to the adaptation principles

	Contribution to resilience						Adaptation phase			Relevance over time					Potential for maladaptation or perverse outcomes				Adaptation Principles				
Action	Protection	Improve connectivity	Improved biodiversity	Increased knowledge	Monitoring	Supporting/improve function	Resilience	Transition	Transformation	2016	2018	2020	2025	2030	Negative impact on other species/systems	Path dependency/lock in trap	perverse outcomes	Exacerbates existing stressors	Leadership	Resilience & transformation	Adaptive Management	Research & Monitoring	Notes
Protect and maintain existing habitat	✓					✓	✓			✓	✓	✓	✓	✓						✓			
Improve condition through weed management			✓			✓	✓			✓	✓	✓	✓	✓	✓	✓				✓			Monitoring for new and emerging weeds suited to hotter and drier conditions
Improve condition through revegetation and fencing projects where appropriate	✓	✓	✓			✓	✓			✓	✓	✓	✓	✓						✓			
Increase the extent of private land managed for habitat values	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓	✓						✓	✓			
Improve connectivity through the development of biolinks		✓					✓	✓		✓	✓	✓	✓	✓						✓			Connectivity can also assist in the movement of pests and disease
Improve connectivity through agricultural and urban landscapes by planting of habitat corridors, and the protection of existing large habitat trees and patches	✓	✓	✓	✓		✓	✓	✓	✓											✓			Education required relating to additional productivity benefits
Maintain a mixed-age class of habitat types through protection and revegetation of different habitat types			✓			✓	✓	✓												✓	✓		
Allow natural regeneration and movement of species to occur through the protection of land and the expansion of the reserve system.		✓	✓			✓		✓	✓										✓	✓			If management of the reserve system is not sufficiently funded, degradation can occur
Protect habitat from the impacts of extreme fire events via fire suppression and allow natural succession of multiple age classes through appropriate mosaic-based fire management	✓					✓	✓	✓	✓		✓	✓	✓	✓					✓	✓	✓		
Facilitate the movement of habitats through translocation and by revegetation projects that account for climate change (using species originating from hotter, drier climates)		✓	✓			✓			✓				✓	✓						✓	✓		Risk of new weed species and loss of species due to competition
Improve resilience by improving habitat in the agricultural and urban matrix via management practices that encourage diversity of native species and protection of ecosystem function		✓	✓			✓		✓	✓			✓	✓						✓	✓			

Table 36: Species, populations and communities – identification of potential adaptation actions, benefits, relevance over time and risks associated with management actions

	Contribution to resilience						Adaptation phase			Relevance over time					Potential for maladaptation or perverse outcomes				Adaptation Principles				
Action	Protection	Improve connectivity	Improved biodiversity	Increased knowledge	Monitoring	Supporting/improve function	Resilience	Transition	Transformation	2016	2018	2020	2025	2030	Negative impact on other species/systems	Path dependency/lock in trap	perverse outcomes	Exacerbates existing stressors	Leadership	Resilience & transformation	Adaptive Management	Research & Monitoring	Notes
Improve connectivity – biolinks and corridors		✓	✓				✓			✓	✓	✓	✓		✓		✓			✓			Connectivity can also facilitate the movement of disease and pests and increase fire risk
Improve diversity and enhance ecological habitats - revegetation			✓				✓			✓	✓	✓	✓							✓			
Reduce existing threats, pest plant and animals and fire	✓						✓	✓		✓	✓	✓	✓							✓			
Build and maintain long-term monitoring programs including citizen science				✓	✓		✓	✓		✓	✓	✓	✓								✓	✓	
Identify refugia				✓			✓	✓		✓	✓	✓	✓				✓					✓	Risk prioritising some species at the expense of others
Re-instate hydrological function						✓	✓	✓	✓	✓	✓	✓	✓				✓	✓		✓			Social pressure to maintain status quo and prioritise social and economic water use over environmental Negative impact on terrestrial species adapted to altered environments
Accept loss – reallocation of resources				✓			✓	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓	✓		Difficult decision to 'give up' on species
Assisted migration of species and communities	✓	✓	✓			✓		✓	✓	✓	✓	✓	✓	✓	✓		✓			✓			Could have adverse effects on other species, communities or systems
Relocation of species internally to the region	✓	✓	✓			✓			✓	✓	✓	✓	✓	✓	✓		✓			✓			Could have adverse effects on other species, communities or systems
Relocation of species externally to the region	✓	✓	✓			✓			✓			✓	✓	✓	✓		✓			✓			Could have adverse effects on other species, communities or systems
Introduction of species from other regions	✓	✓	✓			✓			✓			✓	✓	✓	✓		✓			✓			Could have adverse effects on other species, communities or systems

Table 37: Soil and land - identification of potential adaptation actions, benefits, relevance over time and risks associated with management actions

	Adaptation benefit						Type of adaptation			Relevance					Potential for maladaptation					Adaptation Principles				
Actions	Protection	Improve connectivity	Improved biodiversity	Increased knowledge	Monitoring	Supporting/improving function	Resilience	Transition	Transformation	2016	2018	2020	2025	2030	Negative impact on other species/systems	Path dependency/lock in trap	perverse outcomes	Exacerbates existing stressors	Negative impact on other species/systems	Leadership	Resilience & transformation	Adaptive Management	Research & Monitoring	Notes
Monitor for groundcover targets				✓	✓					✓	✓												✓	
Maintain or exceed groundcover targets through managed grazing	✓	✓	✓			✓	✓	✓	✓			✓	✓	✓							✓	✓		Requires awareness raising
Increase perennial pasture density and diversity	✓	✓	✓			✓	✓	✓	✓				✓	✓							✓			
Soil pH testing				✓	✓					✓													✓	
Lime or dolomite applied to reduce soil acidity	✓					✓	✓	✓			✓											✓		
Soil nutrient testing				✓	✓					✓													✓	
Prescriptive management of soil nutrients	✓	✓	✓			✓	✓	✓			✓										✓	✓		
Integrated pest management	✓	✓	✓	✓	✓	✓	✓	✓	✓					✓						✓	✓	✓	✓	Can also improve connectivity by reducing the hostility of the agricultural matrix
Improved strategies for destocking and protection of vulnerable soils	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓						✓	✓	✓		Possible opportunities for carbon planting
Development of landscape protection strategies for native vegetation and public land	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓						✓			✓	
No cultivation/tillage apart from actual sowing	✓	✓	✓			✓	✓	✓	✓			✓	✓	✓							✓			Requires significant change in culture in some areas
Controlled traffic	✓	✓	✓				✓	✓	✓			✓	✓	✓							✓			
Stubble retained	✓	✓	✓			✓	✓	✓	✓				✓								✓			Requires significant change in culture in some areas
Cover crop or pasture phase in crop rotation	✓	✓	✓			✓	✓	✓	✓					✓							✓			

Glossary

Climate model

A numerical representation of the climate system that is based on the physical, chemical, and biological properties of its components, their interactions, and feedback processes, and that accounts for all or some of its known properties (IPCC, 2014).

Climate projection

A projection of the response of the climate system to emissions or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based upon simulations by climate models. Climate projections are distinguished from climate predictions in order to emphasize that climate projections depend upon the emission/ concentration/radiative-forcing scenario used, which are based on assumptions concerning, e.g., future socioeconomic and technological developments that may or may not be realised and are therefore subject to substantial uncertainty (IPCC 2012).

Climate scenario

A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as about the observed current climate (IPCC 2012).

Climate variability

Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate at all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability) (IPCC 2012).

Drought

A period of abnormally dry weather long enough to cause a serious hydrological imbalance. Drought is a relative term, therefore any discussion in terms of precipitation deficit must refer to the particular precipitation-related activity that is under discussion. A period with an abnormal precipitation deficit is defined as a meteorological drought. A megadrought is a very lengthy and pervasive drought, lasting much longer than normal, usually a decade or more. (IPCC 2012).

Global Climate Model

Global Climate Models, are computer-driven models that are used for projecting weather, understanding climate, projecting seasonal and inter-annual climate and projecting climate change. They are mathematical representations of the real world which simulate processes in the Earth's atmosphere and oceans. There are only a handful of countries in the world that have developed Global Climate Models. Australia has developed the ACCESS1.0, ACCESS1.3 and CSIROMk3.6.0 models.

Exposure

Relates to the influences or stimuli that impact on a system. Exposure is a measure of the projected changes in the climate for the future scenario assessed. It includes both direct stressors, such as increased temperature, and indirect stressors or related events, such as increased frequency of wildfire.

Sensitivity

Reflects the responsiveness of a system to climatic stressors or influences, and the degree to which changes in climate might affect that system in its current form. Sensitive systems are highly responsive to climate and can be significantly affected by small climate changes.

Vulnerability

The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity. This plan is focused on the vulnerability of natural assets to climate change.

Resilience

The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change (IPCC, 2012).

Adaptation

The IPCC refers to adaptation as 'the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects' (IPCC, 2014).

Adaptive capacity

Is the ability of a system to adjust to climate change, including climate variability and extremes, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC, 2014b). The adaptive capacity of a system or society describes its ability to modify its characteristics or behaviour, to cope better with changes in external conditions. The more adaptive a system, the less vulnerable it is. For the purposes of this plan, adaptive capacity will be assigned in terms of the ability of an asset to adjust to climate stressors based on its current state, which may vary from pristine to degraded.

Mitigation

The term mitigation refers to making a condition or consequence less severe. By definition, mitigation is an adaptation response to climate change, aiming to reduce hazards and exposure to potential impacts. In the context of climate change and this plan, mitigation is about taking action to reduce human-induced climate change.

Representative Concentration Pathways

Are used to describe greenhouse gas concentration trajectories. The pathways are used for climate modelling and research. They describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the future. According to the IPCC, the highest RCP (RCP 8.5) assumes a concentration of 1313 ppm CO_2-e by 2100. Projected global mean temperatures associated with this scenario range from 2.6-4.8°C above current temperatures. A mid-range scenario assumes 538 ppm CO_2-e (RCP 4.5), projected increases range from 1.0-2.6°C by 2090 (IPCC, 2013). Currently, global emissions have consistently tracked at or above the highest emissions scenario (RCP 8.5).

Abbreviations

AG	Australian Government
BoM	Bureau of Metrology
CFI	Carbon Farming Initiative
CMA	Catchment Management Authority
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEDJTR	Department of Economic Development, Jobs, Transport and Resources
DELWP	Department of Environment, Land, Water and Planning
DSEWPC	Department of Sustainability, Environment, Water, Population and Communities
ERF	Emissions Reduction Fund
EVC	Ecological Vegetation Community
GCM	Global Climate Model
GHCMA	Glenelg-Hopkins CMA
IPCC	Intergovernmental Panel on Climate Change
MERI	Monitoring, Evaluation, Reporting and Improvement
NCCARF	National Climate Change Adaptation Research Facility
NRM	Natural Resource Management
NRM groups	All community based NRM and environment groups, including Landcare
PV	Parks Victoria
RCP	Representative Concentration Pathways
RCS	Regional Catchment Strategy
SCARP	Southern Slopes Climate Change Adaptation Research Partnership
VEWH	Victorian Environmental Water Holder

Endnotes

[1] ClimateWorks Australia, Low carbon growth plan for Australia, ClimateWorks Australia, Melbourne, 2010

[2] Glenelg Hopkins CMA, Glenelg Hopkins regional catchment strategy, Glenelg Hopkins CMA, Hamilton, 2013.

[3] Victorian Government, Climate change act, Victorian Government, Melbourne, 2010.

[4] Department of Sustainability and Environment, Victorian climate change adaptation plan, Department of Sustainability and Environment, Melbourne, 2013. <http://www.vcc.vic.gov.au/resources/VCS2008/part2.1climatechange.htm>

[5] K Bosomworth, A Harwood, P Leith, P Wallis, Adaptation pathways planning playbook: a guide to developing options for climate change adaptation in NRM, Southern Slopes Climate Change Adaptation Research Partnership (SCARP), RMIT University, University of Tasmania, and Monash University, 2015.

[6] SH Schneider, K Kuntz- Duriseti, Uncertainty and climate change policy, climate change policy: a survey, Washington D.C., 2002.

[7] K Bosomworth, A Harwood, P Leith, P Wallis, Adaptation pathways planning playbook: a guide to developing options for climate change adaptation in NRM, Southern Slopes Climate Change Adaptation Research Partnership (SCARP), RMIT University, University of Tasmania, and Monash University, 2015.

[8] M Dunlop, H Parris, P Ryan and F Kroon, Climate-ready conservation objectives: a scoping study, CSIRO, Canberra, 2013.

[9] M Dunlop, H Parris, P Ryan, F Kroon, Climate-ready conservation objectives: a scoping study, National Climate Change Adaptation Research Facility, Gold Coast, 2013.

[10] M Dunlop, H Parris, P Ryan, F Kroon, Climate-ready conservation objectives: a scoping study, Canberra, 2013.

[11] M Dunlop, H Parris, P Ryan, F Kroon, Climate-ready conservation objectives: a scoping study, Canberra, 2013.

[12] M Dunlop, H Parris, P Ryan, F Kroon, Climate-ready conservation objectives: a scoping study, Canberra, 2013.

[13] IPCC, 5th Assessment report (AR5) Summary for policymakers, IPCC, 2013.

[14] IPCC, 5th Assessment report (AR5) Summary for policymakers, IPCC, 2013.

[15] IPCC, 5th Assessment report (AR5) Summary for policymakers, IPCC, 2013.

[16] IPCC, 5th Assessment report (AR5) Summary for policymakers, IPCC, 2013.

[17] CSIRO, Climate change in Australia projections cluster report – southern slopes, CSIRO and Bureau of Meteorology, Australia, 2015.

[18] Department of Sustainability and Environment, Climate change in the Glenelg Hopkins region, Department of Sustainability and Environment, Melbourne, 2008.

[19] CSIRO, Climate change in Australia projections cluster report – southern slopes, CSIRO and Bureau of Meteorology, Australia, 2015.

[20] CSIRO, Climate change in Australia projections cluster report – southern slopes, CSIRO and Bureau of Meteorology, Australia, 2015.

[21] CSIRO, Climate change in Australia projections cluster report – southern slopes, CSIRO and Bureau of Meteorology, Australia, 2015.

[22] CSIRO, Climate change in Australia projections cluster report – southern slopes, CSIRO and Bureau of Meteorology, Australia, 2015.

[23] CSIRO, Climate change in Australia projections cluster report – southern slopes, CSIRO and Bureau of Meteorology, Australia, 2015.

[24] Spatial Vision, NRM planning for climate change: Discussion paper 1 – impact and vulnerability assessment process, Spatial Vision, Melbourne, 2014.

[25] Spatial Vision, NRM planning for climate change: Discussion paper 1 – impact and vulnerability assessment process, Spatial Vision, Melbourne, 2014.

[26] Spatial Vision, NRM planning for climate change: Discussion paper 1 – impact and vulnerability assessment process, Spatial Vision, Melbourne, 2014.

[27] C Wagg, J Schlapp, Factors relating to social science and its relationship with NRM, RMIT University, Hamilton, 2012.

[28] FHS Chiew, J Teng, J Vase, DA Post, JM Perraud, DGC Kirono, NR Viney, Estimating climate change impact on runoff across southeast Australia: method, results and implications of the modelling method, Water Resources Research 45, 2009.

[29] CSIRO, Climate variability and change in south-eastern Australia: a synthesis of findings from phase 2 of the south east Australian climate initiative (SECI), CSIRO, Canberra, 2012.

[30] F Dyer, S El Sawah, P Lucena-Moya, E Harrison, B Croke, A Tschierschke, R Griffiths, R Brawata, J Kath, T Reynoldson, AJ Jakeman, Predicting water quality and ecological responses, National Climate Change Adaptation Research Facility, Gold Coast, 2013.

[31] SJ Capon, LE Chambers, R Mac Nally, RJ Naiman, P Davies, N Marshall, J Pittock, M Reid, T Capon, M Douglas, J Catford, DS Baldwin, M Stewardson, J Roberts, M Parsons, SE Williams, Riparian ecosystems in the 21st century: hotspots for climate change adaptation? *Ecosystems* 16, 359–381, 2013.

[32] SJ Capon, LE Chambers, R Mac Nally, RJ Naiman, P Davies, N Marshall, J Pittock, M Reid, T Capon, M Douglas, J Catford, DS Baldwin, M Stewardson, J Roberts, M Parsons, SE Williams, Riparian ecosystems in the 21st century: hotspots for climate change adaptation? *Ecosystems* 16, 359–381, 2013.

[33] SJ Capon, LE Chambers, R Mac Nally, RJ Naiman, P Davies, N Marshall, J Pittock, M Reid, T Capon, M Douglas, J Catford, DS Baldwin, M Stewardson, J Roberts, M Parsons, SE Williams, Riparian ecosystems in the 21st century: hotspots for climate change adaptation? *Ecosystems* 16, 359–381, 2013.

[34] Sinclair Knight Mertz, Refuge habitat mapping for drought and fire refuges in the Glenelg River, Crawford River, Wannon River and Mathers Creek, final report, Sinclair Knight Mertz, Melbourne, 2010.

[35] CSIRO, Climate change in Australia projections cluster report – southern slopes, CSIRO and Bureau of Meteorology, Australia, 2015.

[36] Glenelg Hopkins CMA, Glenelg Hopkins regional wetlands status report, Glenelg Hopkins CMA, Hamilton, 2006.

[37] Glenelg Hopkins CMA, Glenelg Hopkins regional catchment strategy 2003-2007, Glenelg Hopkins CMA, Hamilton, 2003.

[38] Glenelg Hopkins CMA, Glenelg Hopkins regional wetlands status Report, Glenelg Hopkins CMA, Hamilton, 2006.

[39] Glenelg Hopkins CMA, Glenelg Hopkins regional wetlands status report, Glenelg Hopkins CMA, Hamilton, 2006.

[40] P Carnell, C Ewers, E Rochelmeyer, R Zavalas, B Hawke, D Ireodiaconou, J Sanderma, P Macreadie, The distribution and abundance of 'blue carbon' within Glenelg Hopkins, Deakin University, Warrnambool, 2015.

[41] C Jin, B Cant, C Todd, Climate change impacts on wetlands in Victoria and implications for research and policy, Arthur Rylah Institute for Environmental Research Technical Report Series no 199, Department of Sustainability and Environment, Heidelberg, Victoria, 2009.

[42] CSIRO, Climate Change in Australia projections cluster report – Southern slopes, CSIRO and Bureau of Meteorology, Australia, 2015.

[43] P Carnell, C Ewers, E Rochelmeyer, R Zavalas, B Hawke, D Ireodiaconou, J Sanderma, P Macreadie, The distribution and abundance of 'blue carbon' within Glenelg Hopkins, Deakin University, Warrnambool, 2015.

[44] NJ Holbrook and J Johnson, Australia's marine biodiversity and resources in a changing climate; a review of impacts and adaptation 2009–2012, National Climate Change Adaptation Research Facility, Gold Coast, 2012.

[45] Department of Climate Change, Climate risks to Australia's coasts: a first pass national assessment, Australian Government, Canberra, 2009.

[46] KL McInnes, I Macadam, GD Hubbert, DJ Abbs, J Balthos, Climate change in eastern Victoria Stage 2 report: The effects of climate change on storm surges, CSIRO Marine and Atmospheric Research Global Environmental Modelling Systems, Aspendale, 2005.

[47] Victorian Coastal Council, Victorian coastal strategy, Victorian Coastal Council, Melbourne, 2014.

[48] Victorian Coastal Council, Victorian coastal strategy, Victorian Coastal Council, Melbourne, 2014.

[49] IPCC, Final Draft, IPCC WGII AR5 Chapter 5, Coastal systems and low-lying areas, 2013.

[50] IPCC, Final Draft, IPCC WGII AR5 Chapter 5, Coastal systems and low-lying areas, 2013.

[51] Department of Climate Change, *Climate change risks to Australia's coast: A first pass national assessment,* Canberra: Australian Government, 2009

[52] Department of Climate Change, *Climate change risks to Australia's coast: A first pass national assessment,* Canberra: Australian Government, 2009

[53] C Jin, B Cant, C Todd, *Climate change impacts on wetlands in Victoria and implications for research and policy*, Arthur Rylah Institute for Environmental Research Technical Report Series no. 199. Department of Sustainability and Environment. Heidelberg, 2009.

[54] Department of Sustainability and Environment, The Victorian coastal hazard guide, Department of Sustainability and Environment, Melbourne, 2012.

[55] P Bruun, Coast erosion and the development of beach profiles. Technical Memorandum, vol 44, Beach Erosion Board, Corps of engineers, 1954.

[56] J Cooper and O Pilkey, Sea-level rise and shoreline retreat: time to abandon the Bruun Rule, Global and Planetary Change 43, 2004.

[57] DR Cahoon, DJ Reed, JW Day Jr, Estimating shallow subsidence in microtidal salt marshes of the southeastern Unite State, Marine Geology, 1995.

[58] Victorian Coastal Council, Victorian coastal strategy, Victorian Government, Australia, 2008.

[59] A Lukasiewicz, CM Finlayson, J Pittock, Identifying low risk climate change adaptation in catchment management while avoiding unintended consequences, National Climate Change Adaptation Research Facility, Gold Coast, 2013.

[60] CSIRO, Climate change in Australia projections cluster report – southern slopes, CSIRO and Bureau of Meteorology, Australia, 2015.

[61] KL McInnes, I Mcadam, G Hubbert, J O'Grady, An assessment of current and future vulnerability to coastal inundation due to sea-level extremes in Victoria, southeast Australia. *International Journal of Climatology*, 33(1), pp 33–47, 2013.

[62] JW Fourqurean, CM Duarte, H Kennedy, N Marba, M Holmer, MA Mateo, ET Apostolaki, GA Kendrick, J Krause-Jensen, KJ McGlathery, O Serrano, Seagrass ecosystems as a globally significant carbon stock, Nature Geoscience, 2012.

[63] P Carnell, C Ewers, E Rochelmeyer, R Zavalas, B Hawke, D Ireodiaconou, J Sanderma, P Macreadie, The distribution and abundance of 'blue carbon' within Glenelg Hopkins. Deakin University, Warrnambool, 2015.

[64] SD Ling, CR Johnson, SD Frusher, KR Ridgway, Overfishing reduces resilience of kelp beds to climate-driven catastrophic phase shift. Proceedings of the National Academy of Sciences of the United States of America, 2009.

[65] NJ Holbrook, J Johnson, Australia's marine biodiversity and resources in a changing climate: a review of impacts and adaptation 2009–2012, National Climate Change Adaptation Research Plan, 2012.

[66] NJ Holbrook and J Johnson, Australia's marine biodiversity and resources in a changing climate; a review of impacts and adaptation 2009–2012, National Climate Change Adaptation Research Facility, Gold Coast, 2012.

[67] ES Poloczanska, AJ Hobday and AJ Richardson (Eds) Marine climate change in Australia: impacts and adaptation responses 2012 report card, 2012.

[68] ES Poloczanska, AJ Hobday and AJ Richardson (Eds) Marine climate change in Australia: impacts and adaptation responses 2012 report card, 2012.

[69] J Klemke and H Arundel (Eds), Implications of future climate for Victoria's marine environment, Glenelg Hopkins Catchment Management Authority, Australia, 2013.

[70] ES Poloczanska, AJ Hobday and AJ Richardson (Eds) Marine climate change in Australia: impacts and adaptation responses 2012 report card, 2012.

[71] J Klemke and H Arundel (Eds), Implications of future climate for Victoria's marine environment, Glenelg Hopkins Catchment Management Authority, Australia, 2013.

[72] J Klemke and H Arundel (Eds), Implications of future climate for Victoria's marine environment, Glenelg Hopkins Catchment Management Authority, Australia, 2013.

[73] MPE Madin, NC Ban, ZA Doubleday, TH Holmes, GT Pecl, F Smith, Socio-economic and management implications of range-shifting species in marine systems, Global Environmental Change, Volume 22, Issue 1,137-146, 2012.

[74] Antarctic Climate and Ecosystems CRC, Report card – Southern Ocean acidification, 2010.

[75] ES Poloczanska, AJ Hobday and AJ Richardson (Eds) Marine climate change in Australia: impacts and adaptation responses 2012 report card, 2012

[76] M Byrne, SM Prober, EH McLean, DA Steane, WD Stock, BM Potts, RE Valliancourt, Adaptation to climate in widespread eucalypt species, National Climate Change Adaptation Research Facility, Gold Coast, 2011.

[77] Antarctic Climate and Ecosystems CRC, Report card – Southern Ocean acidification, 2010.

[78] NJ Holbrook and J Johnson, Australia's marine biodiversity and resources in a changing climate: a review of impacts and adaptation 2009–2012, National Climate Change Adaptation Research Facility, Gold Coast, 2012.

[79] Glenelg Hopkins Catchment Management Authority, Glenelg Hopkins regional catchment strategy, Glenelg Hopkins Catchment Management Authority, Hamilton, 2013.

[80] W Steffen, A Burbridge, L Hughes, R Kitching, D Lindenmayer, W Musgrave, M Stafford Smith, P Werner, Australia's biodiversity and climate change: summary for policy makers, 2009.

[81] J Memmott, PG Craze, NM Waser, MV Price, Global warming and the disruption of plant-pollinator interactions, Ecology Letters 10, 710-717, 2007.

[82] NJ Holbrook and J Johnson, Australia's marine biodiversity and resources in a changing climate: a review of impacts and adaptation 2009–2012, National Climate Change Adaptation Research Facility, Gold Coast, 2012.

[83] C Parmesan, G Yohe, A globally coherent fingerprint of climate change impacts across natural systems, Nature 421, 37–42, 2003.

[84] VAJ Doerr, KJ Williams, M Drielsma, ED Doerr, J Love, A Langston, S Low Choy, G Manion, EM Cawsey, HM McInnes, T Javanovic, D Crawfors, M Austin, S Ferrier, Designing landscapes for biodiversity under climate change, National Climate Change Adaptation Research Facility, Gold Coast, 2013.

[85] VAJ Doerr, KJ Williams, M Drielsma, ED Doerr, J Love, A Langston, S Low Choy, G Manion, EM Cawsey, HM McInnes, T Javanovic, D Crawfors, M Austin, S Ferrier, Designing landscapes for biodiversity under climate change, National Climate Change Adaptation Research Facility, Gold Coast, 2013.

[86] TH Booth, KJ Williams, Developing biodiverse plantings suitable for changing climatic conditions 1: underpinning scientific methods, Ecological Management and Restoration, vol 13, 2012

[87] TH Booth, KJ Williams, Developing biodiverse plantings suitable for changing climatic conditions 1: underpinning scientific methods, Ecological Management and Restoration, vol 13, 2012

[88] CSIRO, Climate change in Australia projections cluster report – southern slopes, CSIRO and Bureau of Meteorology, Australia, 2015.

[89] NCCARF Terrestrial Biodiversity Network, Terrestrial report card 2013: Climate change impacts and adaptation on Australian biodiversity, National Climate Change Adaptation Research Facility, Gold Coast, 2013.

[90] C Parmesan, and G Yohe, A globally coherent fingerprint of climate change impacts across natural systems, Nature 421, 37–42, 2003.

[91] C Parmesan, Ecological and evolutionary responses to recent climate change: annual review of ecology, evolution and systematics 37, 637–669, 2006.

[92] ID Lunt, M Byrne, JJ Hellmann, NJ Mitchell, ST Garnett, MW Hayward, Using assisted colonisation to conserve biodiversity and restore ecosystem function under climate change, Biological Conservation 157, 172–177, 2013.

[93] SM Prober, KR Thiele, PW Rundel, CJ Yates, SL Berry, M Byrne, L Christidis, CR Gosper, PF Grierson, KL Lemson, T Lyons, C Macfarlane, MH O'Connor, JK Scott, RJ Standish, WD Stock, EJB van Etten, GW Wardell-Johnson, A Watson, Facilitating adaptation of biodiversity to climatic change: a conceptual framework applied to the world's largest Mediterranean-climate woodland, Climatic Change 110 (1-2), 227–248, 2012.

[94] S Garnett, D Franklin, Climate change adaptation plan for Australian birds, CSIRO, Collingwood, 2014

[95] LE Chambers, R Altwegg, C Barbraud, P Barnard, LJ Beaumont, RJM Crawford, JM Durant, L Hughes, MR Keatley, M Low, PC Morellato, ES Poloczanska, V Ruoppolo, RET Vanstreels, EJ Woehler, AC Wolfaardt, Phenological changes in the southern hemisphere, PLoS ONE, 2013.

[96] M Dunlop, H Parris, P Ryan, F Kroon, Climate-ready conservation objectives: a scoping study, Canberra, 2013.

[97] JK Scott, BL Webber, H Murphy, N Ota, DJ Kriticos, B Loechel, AdaptNRM Weeds and climate change: supporting weed management adaptation, Canberra, 2014.

[98] LP Shoo, Planning for biodiversity in future climates, Science 327: pp 1452, 2010.

[99] CSIRO, Interim climate projection statement, CSIRO, Canberra, 2013.

[100] Department of Primary Industries, Climate change impacts and adaptation responses for south-west Victoria's primary industries, a DPI VCCAP discussion paper, Department of Primary Industries, Melbourne 2010.

[101] B Cullen, I Johnson, R Eckard, G Lodge, R Walker, R Rawnsley, and M McCaskill, Climate change effects on pasture systems in south-eastern Australia. In: Crop and pasture science, CSIRO Publishing, 2009.

[102] E Liu & P Fitzsimons, Regional economic profile of south west Victoria, Victorian Department of Primary Industries, Melbourne, 2009.

[103] Water and Land use Change Study Steering Committee and Sinclair Knight Merz, Water and land use change study, Water and Land use Change Study Steering Committee and Sinclair Knight Merz, Hamilton, 2005

[104] GJ O'Leary, B Christy, A Weeks, J Nuttal, P Riffkin, C Beverly, G Fitzgerald, Biophysical modelling: likely response of wheat crop yield to climate change across Victoria, VCCAP Project Biophysical Modelling Theme Final Report, Victorian Department of Primary Industries, Horsham, 2010.

[105] V Sposito, C Pelizaro, K Benke, M Anwar, D Rees, M Elsley, G O'Leary, R Wyatt, B Cullen, Climate change impacts on agriculture and forestry systems in south west Victoria, Victorian Department of Primary Industries, Melbourne, 2008.

[106] C Stokes, M Howden, Adapting Agriculture to climate change – preparing Australian agriculture, forestry and fisheries for the future, CSIRO publishing, Victoria, 2010.

[107] N Tostovrsnik, M Morris, R Eckard, G O'Leary, C Pettit, P Fitzsimons, B Christy, J Sandall, L Soste, V Sposito, Climate change impacts and adaptation responses for south-west Victoria's primary Industries, Victorian Department of Primary Industries, Victoria, 2010.

[108] J Nuttall, R Armstrong, M Crawford, Climate change – identifying the impacts on soil health in Victoria, Department of Primary Industries, Victoria, 2007.

[109] R MacEwan, Soil health for Victoria's agricultural context, terminology and concepts, Department of Primary Industries, 2007

[110] J Nuttall, R Armstrong, M Crawford, Climate change – identifying the impacts on soil health in Victoria, Department of Primary Industries, Victoria, 2007.

[111] J Nuttall, R Armstrong, M Crawford, Climate change – identifying the impacts on soil health in Victoria, Department of Primary Industries, Victoria, 2007.

[112] E Brevik, The potential of climate change on soil properties and processes and corresponding influence of food security, Agriculture, 2013

[113] RD Bardgett, C Freeman, NJ Ostle, Microbial contributions to climate change through carbon cycle feedbacks, The ISME Journal (2008) 2, 805–814, 2008.

[114] J Nuttall, R Armstrong, M Crawford, Climate change – identifying the impacts on soil health in Victoria, Department of Primary Industries, Victoria, 2007.

[115] G Nelson, Climate change: impact on agriculture and costs of adaptation, International Food Policy Research Institute, Asian Development Bank, 2009.

[116] R Garnaut, The Garnaut climate change review final report, Australian government, Canberra, 2008.

[117] C Stokes, M Howden, Adapting agriculture to climate change: preparing Australian agriculture, forestry and fisheries for the future, CSIRO Publishing, 2010

[118] Glenelg Hopkins CMA, Glenelg Hopkins soil health strategy 2014–2019, Glenelg Hopkins CMA, Hamilton, 2014.

[119] Glenelg Hopkins CMA, Glenelg Hopkins soil health strategy 2014–2019, Glenelg Hopkins CMA, Hamilton, 2014.

[120] Parliament of Australia, Carbon sequestration, viewed 20 January 2016 http://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/Browse_by_Topic/ClimateChange/responses/mitigation/Carbon_sequestration .

[121] J Norris, S Arnold, T Fairman, An indicative estimate of carbon stocks on Victoria's publicly managed land using the FullCAM carbon accounting model, Australian Forestry, 2010.

[122] CSIRO, Marine and coastal carbon biogeochemistry cluster (coastal carbon cluster), viewed 2 June 2014 http://www.csiro.au/Coastal-Carbon-Cluster.

[123] CSIRO, Marine and coastal carbon biogeochemistry cluster (coastal carbon cluster), viewed 2 June 2014 http://www.csiro.au/Coastal-Carbon-Cluster.

[124] CSIRO, Marine and coastal carbon biogeochemistry cluster (coastal carbon cluster), viewed 2 June 2014 http://www.csiro.au/Coastal-Carbon-Cluster.

[125] ClimateWorks Australia, Low carbon growth plan for Australia, ClimateWorks Australia, Melbourne, 2010.

[126] ClimateWorks Australia, Low carbon growth plan for Australia, ClimateWorks Australia, Melbourne, 2010.

[127] ClimateWorks Australia, Low carbon growth plan for Australia, ClimateWorks Australia, Melbourne, 2010.

[128] ClimateWorks Australia, Low carbon growth plan for Australia, ClimateWorks Australia, Melbourne, 2010.

[129] Department of the Environment, Emissions reduction fund methods, Department of the Environment, Canberra, viewed 18 May 2015, <http://www.environment.gov.au/climate-change/emissions-reduction-fund/methods>

[130] DS Powlson, AP Whitmore, KWT Goulding, Soil carbon sequestration to mitigate climate change: a critical re-examination to identify the true and the false, Journal compilation © 2011 British Society of Soil Science, European Journal of Soil Science, 62, 42–55, 2011.

[131] J Sanderman, R Farquharson, J Baldock, Soil carbon sequestration potential: a review for Australian agriculture, CSIRO Sustainable Agriculture National Research Flagship, 2010.

[132] S Barlow, P Grace, R Keenan, R Eckard, B Henry, Australian Government House of Representatives. Standing Committee on Climate Change, Environment and the Arts. Submission to inquiry into the carbon farming initiative bills, 2011.

[133] Victorian Government, Environment and Natural Resources Committee inquiry into soil carbon sequestration in Victoria, Victorian Government, 2010.

[134] P Polglase, A Reeson, C Hawkins, K Paul, J Carwardine, A Siggins, J Turner, D Crawford, T Jovanovic, T Hobbs, K Opie, A Almeida, Opportunities for carbon forestry in Australia: economic assessment and constraints to implementation, CSIRO, Canberra, 2011.

[135] JW Fourqurean, CM Duarte, H Kennedy, N Marba, M Holmer, MA Mateo, ET Apostolaki, GA Kendrick, J Krause-Jensen, KJ McGlathery, O Serrano, Seagrass ecosystems as a globally significant carbon stock. Nature Geoscience, 5, 2012 505–509, DOI 10.1038/ngeo1477.

[136] MA Mateo, J Romero, M Perez, MM Littler, DS Littler, Dynamics of millenary organic deposits resulting from the growth of the Mediterranean seagrass Posidonia oceanica. Estuarine, Coastal and Shelf Science, 44, 103–110, 1997 DOI 10.1006/ecss.1996.0116.

[137] MO Pedersen, O Serrano, MA Mateo, M Holmer, Temperature effects on decomposition of a Posidonia oceanica mat. Aquatic Microbial Ecology, 65, 169–182, 2011, DOI 10.3354/ame01543.

[138] E Gacia, CM Duarte, Sediment retention by a Mediterranean Posidonia oceanica meadow: the balance between deposition and resuspension. Estuarine, Coastal and Shelf Science, 52, 505–514, 2001, DOI 10.1006/ecss.2000.0753.

[139] NSW Agawin, Cm Duarte CM, Evidence of direct particle trapping by a tropical seagrass meadow. Estuaries, 25, 1205–1209, 2002.

[140] IE Hendriks, T Sintes, TJ Bouma, CM, Experimental assessment and modeling evaluation of the effects of the seagrass Posidonia oceanica on flow and particle trapping. Marine Ecology Progress Series, 356, 163–173, 2008 DOI 10.3354/meps07316.

[141] H Kennedy, J Beggins, CM Duarte, JK Fourqurean, M Holmer, N Marba, JJ Middelburg, Seagrass sediments as a global carbon sink: isotopic constraints. Global Biogeochemical Cycles, 24, GB4026, 2010, DOI 10.1029/2010GB003848.

[142] L Pendleton, DC Donato, BC Murray, S Crooks, WA Jenkins, S Sifleet, C Craft, JW Fourqurean, JB Kauffman, N Marba, P Megonigal, E Pidgeon, D Herr, D Gordon, A Baldera A, Estimating global 'blue carbon' emissions from conversion and degradation of vegetated coastal ecosystems. Plos One, 7, 1–7, 2012.

[143] PI Macreadie, AR Hughes, DL Kimbro, Loss of 'blue carbon' from coastal salt marshes following habitat disturbance, Plos One, 8, 2013.

[144] IPCC, Final Draft, IPCC WGII AR5 Chapter 5; Coastal systems and low-lying areas, 2013

[145] I Valiela, JL Bowen, JK York, Mangrove forests: one of the world's threatened major tropical environments, Bioscience, 51, 807-815, 2001.

[146] DM Alongi, Present stated and future of the world's mangrove forests. Environmental Conservation, 29, 331-349, 2002.

[147] P Carnell, C Ewers, E Rochelmeyer, R Zavalas, B Hawke, D Ireodiaconou, J Sanderma, P Macreadie, The distribution and abundance of 'blue carbon' within Glenelg Hopkins. Deakin University, Warrnambool, 2015.

[148] V Engle, E G Jobbagy, M Stielglitz, M Williams, R B Jackson, Hydrological consequences of Eucalyptus afforestation in the argentine Pampas, Water Resources Vol 41, 2005.

[149] K A Farley, E G Jobbagy, R B Jackson, Effects of afforestation on water yield: a global synthesis with implications for policy, Global Change Biology, 2005.

[150] RG Benyon, T M Doody, S Theiveyanathan, V Koul, Plantation forest water use in southwest Victoria, Technical Report No. 164, 2008

[151] Glenelg Hopkins CMA, WatLUC water and land use change study, stage 2 community report, Water and Land Use Change Study Steering Committee and Sinclair Knight Merz, 2005.

[152] LC Hamilton, A review of carbon sequestration in vegetation and soils: options, opportunities and barriers for the southern slopes cluster NRMS, Southern Slopes Climate Change Adaptation Research Partnership, 2014.

[153] P Polglase, A Reeson, C Hawkins, K Paul, A Siggins, J Turner, D Crawford, T Jovanovic, T Hobbs, K Opie, J Carwardine A Almeida, Opportunities for carbon forestry in Australia: economic assessment and constraints to implementation, 2011.

[154] N J Enright, J B Fontane, Climate change and the management of fire-prone vegetation in southwest and southeast Australia, Geographical Research, 2013.

[155] KI Paul, A Reeson, P Polglase, N Crossman, D Freudenberger, C Hawkins, Economic and employment implications of a carbon market for integrated farm forestry and biodiverse environmental plantings, Land Use Policy, 2013.

[156] Australian Department of Sustainability, Environment, Water, Population and Communities, The role of wetlands in the carbon cycle, 2012.

[157] Ramsar Secretariat and Scientific and Technical Review Panel and the Secretariat of the CBD, Water, wetlands, biodiversity and climate change, Switzerland, 2007.

[158] Australian Department of Sustainability, Environment, Water, Population and Communities The role of wetlands in the carbon cycle, 2012.

[159] Glenelg Hopkins CMA, Glenelg Hopkins waterway strategy 2014–2022, Glenelg Hopkins CMA, Hamilton, 2014.

[160] CSIRO, Climate change in Australia projections cluster report – southern slopes, CSIRO and Bureau of Meteorology, Australia, 2015.