LAND CAPABILITY ASSESSMENT

Of Glenelg Hopkins Catchment

Technical Report: **Pastures**

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The likely climate change futures presented in this report are based on the development of scenarios which are consistent with climate change scenarios developed by the Intergovernmental Panel on Climate Change (IPCC). They represent a range of possible futures for the Glenelg Hopkins Catchment Region, Victoria, Australia, although none of them may ever eventuate. Observed values of key climatic variables are current at the time of writing; however, new information is being made available on a frequent basis that may impact upon some of the conclusions presented in this report.

PLEASE NOTE: This technical report outlines the land suitability modelling under climate change scenarios undertaken in this project. The report is intended to provide sufficient information to allow other researchers to replicate the modelling. For a succinct overview of the results of the modelling and the implications of the land suitability assessments for the region, please refer to the accompanying 'Summary Report'.

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1. Executive Summary

Land Capability or Suitability Assessment of the Glenelg Hopkins Catchment is a climate change adaptation project aimed at informing government (Local and State), the agricultural sector and the broader community, of the possible impacts of climate change on key commodities produced across the study region. The information has been developed to

1) Generate and communicate specific long-term data, information and strategic plans that enable Local Government Authorities and the agriculture sector in the Glenelg Hopkins catchment to adapt to climate change effectively with a focus on regional development, infrastructure and agricultural industry transformation

2) Reduce risks of soil degradation through farming practices inappropriate to future warmer, drier climate conditions.

The project has been co-funded by the Glenelg Hopkins CMA with the support of the Australian Government's National Landcare Programme, Southern Grampians Shire Council and Deakin University. This report outlines an analysis of the potential implications of regional climate change on pastures, through GIS modelling of grasses: perennial ryegrass (winter active), phalaris (winter active) and panic grass (summer active); herbs: plantain (winter active); and legumes: lucerne (summer active). An expert systems-based modelling approach was used that considers climatic, soil and landscape parameters to map expected yield across the region. The models and maps were validated with local farmers, farming groups and agronomists then modified according to their feedback, before running the models again with climate change projection data to understand how projected variability in climate might influence the expected yield (in tonnes of dry matter per hectare per year [t DM/ha/yr]) and subsequently land suitability. The outputs are intended for strategic, regional-level decision making in relation to agricultural development, infrastructure and water. So, it is important to understand the assumptions and caveats associated with the modelling before interpreting the maps, which are covered in the body of the report. Also, the maps and associated information may assist to inform on-farm adaptation, to guide breeding programs and regional trials, among other more localised issued. But, decisions at such localised or specific levels will need to be informed by additional, more targeted research outside the scope of this project.

According to the available climate projection data, the region will become drier in the winter, particularly in the north-east part of the catchment, but with rainfall likely to increase in the summer. Hotter summers in the north are also likely to impact pasture production. Projected changes to the values of key climatic variables, such as rainfall and temperature, could potentially impact the optimal pasture growth conditions. Increased temperatures could have negative impacts in terms of increased heat and water stress due to higher evapotranspiration. Higher incidence of summer rainfall events have the potential to stimulate summer active species.

The modelling indicates significant shifts in suitability that vary between pasture species depending on their heat and drought tolerance, and also dormancy. Species with lower water requirements and deep taproots are likely to be more persistent, but will require less intensive grazing management (ex. rotational grazing) allowing for sufficient rest periods. This report looks at alternative commodities that are summer active, often more drought and heat resistant than the currently grown species, or that have a high market value, in order to encourage more regional trials and inform adaptation efforts. Needless to say, new cultivars of currently favoured ryegrass and phalaris species are constantly being developed, increasing their persistence and applicability but could not be included in the current modelling.

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2. List of Figures

3. List of Acronyms

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
AHP	Analytical Hierarchy Process
AR5	Fifth Assessment Report (on climate change from International Panel on Climate Change)
BoM	Bureau of Meteorology
CMA	Catchment Management Authority
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEM	Digital Elevation Model
DPI NSW	Department of Primary Industries, New South Wales
DPIPWE	Department of Primary Industries, Parks, Water and Environment, Tasmania
DSITIA	Department of Science, Information Technology and Innovation, Queensland
FAO	Food and Agriculture Organisation of the United Nations
GCM	Global Climate Model
GHC	Glenelg Hopkins Catchment
GHG	Greenhouse Gas
GIS	Geographical Information Systems
GRDC	Grains Research & Development Corporation
IPCC	International Panel on Climate Change
LSA	Land Suitability Assessment
MCA	Multi Criteria Analysis
NASA	National Aeronautics and Space Administration
PNS	Permanently Not Suitable
RCP	Representative Concentration Pathways
RIRDC	Rural Industries Research & Development Corporation
SILO	Scientific Information for Land Owners
SRTM	Shuttle Radar Topography Mission
TNS	Temporarily Not Suitable
USGS	United States Geological Survey
VIC	The State of Victoria
VLUIS	Victorian Land Use Information System
VRO	Victorian Resources Online
WA	The State of Western Australia
WMO	World Meteorological Organisation
WorldClim	Global Climate Data

4. Key Definitions

Analytical Hierarchy Process	Is a set of biophysical variables (criteria) that determine the growth and production of the selected agricultural commodity, arranged into a hierarchical order, which forms a decision making structure that can be evaluated by assigning weights to each criteria
Baseline	Baseline is a description of historical biophysical attributes of the Glenelg Hopkins catchment for 1960 – 1990, supported by available historical data for that period and agreed upon during validation stages of this project
Climate Change Projections	Show how climate and its variables such as temperature and rainfall are likely to change in the future based on the outputs of global climate models and their mathematic depiction of both atmospheric and oceanic circulation systems subjected to different types and levels of forcings
Multi Criteria Analysis	Its primary focus is combining biophysical data with expert knowledge to formulate a single suitability index class
Land Suitability or Capability	examines the degree of land suitability for the growth (cultivation or cropping) of the agricultural commodity of interest while reaching an adequate yield for each commodity
Representative Concentration Pathways	Are a set of scenarios developed by the International Panel on Climate Change for four plausible gas concentrations dependent on the level of anthropogenic forcing. They range from RCP 2.6 with a decline in emissions through RCP 4.5 of low increase of emissions to RCP 8.5 of high emissions pathway that is currently being followed
Validation	Is a model and suitability map verification process of face-to-face interviews with local stakeholders (predominantly farmers, Landcare groups and agronomists)
Waterlogging Susceptibility	Is defined by a set of soil attributes influencing the likelihood of the soil profile to get saturated with water, resulting in insufficient oxygen in the pore space for plant roots to be able to adequately respire

5. Acknowledgements

The Deakin Project Team would like to acknowledge the various contributions that made this research possible.

We acknowledge and thank the Victorian Government, via the Department of Economic Development, Jobs, Transport and Resources (and its predecessor, the Department of Environment and Primary Industries), the Southern Grampians Shire Council, the Glenelg Hopkins Catchment Management Authority and the Australian Government for providing funding under the National Landcare Programme, and for providing support and input for the model validation.

We would also like to thank the Project Control Group for their time, guidance and encouragement over the course of the project. Each participating organisation made a substantial in kind contribution to the project by supplying staff who contributed a significant amount of their time over the course of the research. Some members of the Project Control Group went further by organising meetings with local farmers and accompanying the project team during model-validation sessions. The research would not have been possible without this key input from the Project Control Group.

We are very grateful to the farmers, agronomists and other locals that donated their valuable time to assess our models and maps and to make recommendations on how to improve them. This step is what distinguishes this research from the many, purely academic modelling exercises that can be found in the scientific literature and so we are indebted to the generous Glenelg Hopkins catchment residents who provided their local knowledge.

Finally, we would like to specifically thank Kellie Nilsson, Richard Murphy and Jonathan Jenkin, for their expert project management and facilitation skills respectively. The Deakin project group have conducted many similar studies around the state over many years but none have been managed and run as well as this project.

6. Introduction

A comprehensive account of the project background will follow the publication of all three commodity group technical reports (cropping, pastures and horticulture) in the final project background report. The following introductory, climate change and methodology chapters will be adapted and expanded upon in that project report.

The outputs of the project include climate projections for the region, maps showing the climate change impacts and opportunities for commodity production, and regionally-focused strategic plans that explicitly incorporate local knowledge and aspirations in order to maximise both economic and environmental outcomes with an emphasis on soil health. The input given by farmers during face-to-face round of consultation is essential to validate the results of land suitability assessment or LSA models for each commodity. Any input on commodity-specific growing requirements is reflected in the final regional maps of land suitability and subsequently in this report.

7. Project Scope and Strategic Objectives

The land suitability assessment part of this project, as the main subject of this report, aims to determine the extent of climate change impacts on the performance of selected pasture commodities. A list of 5 pasture species has been selected by the Project Control Group to include commodities already grown in the region as well as a number of potential future additions to the south west pasture systems. Surface water availability will decrease and temperatures will increase. To sustain agricultural livelihoods, it is therefore imperative that farm-level adaptation measures are supported by strategic planning using region-specific impact information, regional development and council-supported business development in order to assist agricultural transformation.

In the above context, the main aim of this project is to generate and communicate specific long-term data, information and strategic plans that enable Local Government Authorities and the agriculture sector in the Glenelg Hopkins catchment to adapt to climate change effectively with a focus on regional development, infrastructure and agricultural industry transformation. The project has synthesised existing climate change and agricultural research as well as spatial data, and generated new information, to establish decision-making tools for Local Government and CMA adaptation planning.

8. Climate Change & Agriculture

Australian agriculture and its key industries are being exposed to rapid, intensive and extensive transformations associated with the influences of various drivers of change. The main driving forces include globalisation, climate change, new markets and trade arrangements, competition for natural resources (land and water), and socio-cultural and organisational changes. Consequently, our farmers are facing unprecedented pressures and uncertainties. At the same time, exciting new opportunities are emerging. These changes will be far reaching and will have a profound and lasting impact on agriculture and forestry production in Australia, in general, and Victoria, in particular, over the coming decades.

There is wide acceptance that human well-being is linked to land uses that can sustain a diversity of ecosystem services (Reid et al., 2005). Many countries are therefore re-evaluating how they can retain high levels of agricultural food production whilst balancing other demands for the land resource such as maintaining good drinking water quantity and quality, limiting Green-House Gas (GHG) emissions, or safe-guarding the socio-cultural and economic benefits of the their landscapes (Brown et al., 2008). Unfolding changes in climatic conditions are of particular importance (Flannery, 2005, Ruth et al., 2006, Reid et al., 2005, IPCC, 2007b, IPCC, 2013).

8.1 Climate Change Implications for Plant Growth

The geographic (spatial) distribution of plant species, vegetation types and pasture types demonstrate the strong influence that climate has on plant growth. Solar radiation, temperature and precipitation (in turn impacting on water availability) and seasonal patterns are key determinants of plant development through a variety of direct and indirect effects. Other climatic characteristics, such as wind speed and storm intensity and frequency, are also major influences. Plant function is directly linked to climate and atmospheric carbon dioxide (CO_2) concentrations. On the shortest temporal and smallest spatial scales, the climate affects the plant's immediate environment and thus directly affects physiological processes. On longer time and larger spatial scales, the climate influences the distribution of species and community composition and can determine what pastures can be viably grown in managed agro-ecosystems. Plant growth also influences the local, regional and global climate through the exchanges of energy and gases between the plants and the air around them (Morison and Morecroft, 2008, Hillel and Rosenzweig, 2011, Stokes and Howden, 2010).

There is a rapidly growing number of well-documented instances of change in ecosystems due to recent (and most likely human-induced) climate change (Steffen, 2009, Reid et al., 2005, Callaghan et al., 2004, Steffen et al., 2006). Overall, the Intergovernmental Panel on Climate Change (IPCC, 2007b, IPCC, 2013) concluded that "from collective evidence, there is high confidence that recent regional changes in temperature have had discernible impacts on many physical and biological systems". These recent climate changes are likely to accelerate as human activities continue to perturb the climate system and many reviews have made predictions of serious consequences for ecosystems.

Climate change poses major scientific and practical challenges. Our comprehension of plant responses to future climate must be built on a better understanding of the climate system itself, especially at the regional scale. Plant production needs to be maximised to overcome the new, or altered, climatic conditions on food and fibre production in the face of continuing population growth, with a focus on sustainable actions. The sustainability of agricultural and forestry production systems needs to be improved by reducing GHG emissions and the use of fossil fuels and by reducing water and nutrient consumption. The management of natural resources must be adapted to conserve biodiversity in changing environmental conditions.

8.2 Regional Scale Climate Change

CSIRO and the Bureau of Meteorology (BoM) published climate change projections for Australia and its States in October 2007, with an update in 2015. (CSIRO and BOM, 2007, CSIRO and BOM, 2015). These reports provide the information on observed climate change in the country and its likely causes, as well as updated projections of change in the key climatic variables and other aspects of climate that can be expected over the coming decades. Projections are formulated for the years 2030, 2050 and 2070.

At Glenelg Hopkins catchment scale, climate change scenarios were visualised and reported upon in the previous report "Analysis of Climate Projections for GHC region" in September 2016. The baseline climate data has been derived from an averaged overlay of SILO and WorldClim datasets. SILO data has a resolution of 5 km^2 and provides historical climate data (precipitation; maximum, minimum and mean temperature) from Australian Bureau of Meteorology. (Department of Science, Information Technology and Innovation 2016) WorldClim data has a resolution of 1 km^2 and was created by interpolating average monthly values by combining data from a number of global as well as local Australian databases. (Hijmans et al. 2005) The output baseline layers have a 1 km^2 resolution, to be comparable with the projection datasets. Values for 2030, 2050 and 2070 have been derived using a 1 km^2 ACCESS 1.0 global climate model developed for Australia by CSIRO-BOM. This model represents the most recent Representative Concentration Pathways (RCP) scenarios. Outputs for this climate change scenario projects by comparison to the baseline year that there will likely be:

- An increase of between 3°C to 4°C in the average maximum temperature for the high emissions scenario RCP 8.5.
- An increase of between 1.5°C to 2°C in the average mean temperature for the high emissions scenario RCP 8.5.
- An increase of between 1°C to 2°C in the average minimum temperature for the high emissions scenario RCP 8.5.
- A decrease of about 50mm per year to 100mm per year in the total annual rainfall for the high emissions scenario RCP 8.5.

Figure 1 shows a projected overall decrease in rainfall over seasons, with a potential for a slight increase in summer under the low emissions pathway RCP 4.5 and high emissions pathway RCP 8.5. Figure 2 demonstrates the likely future increase in mean, maximum and minimum temperatures alike, under both low and high emissions scenarios RCP 4.5 and 8.5, respectively. The extent of changes is significant, suggesting high variability of future climate. The averaged values suggest an increase across all seasons, with the highest rise in summer temperatures.

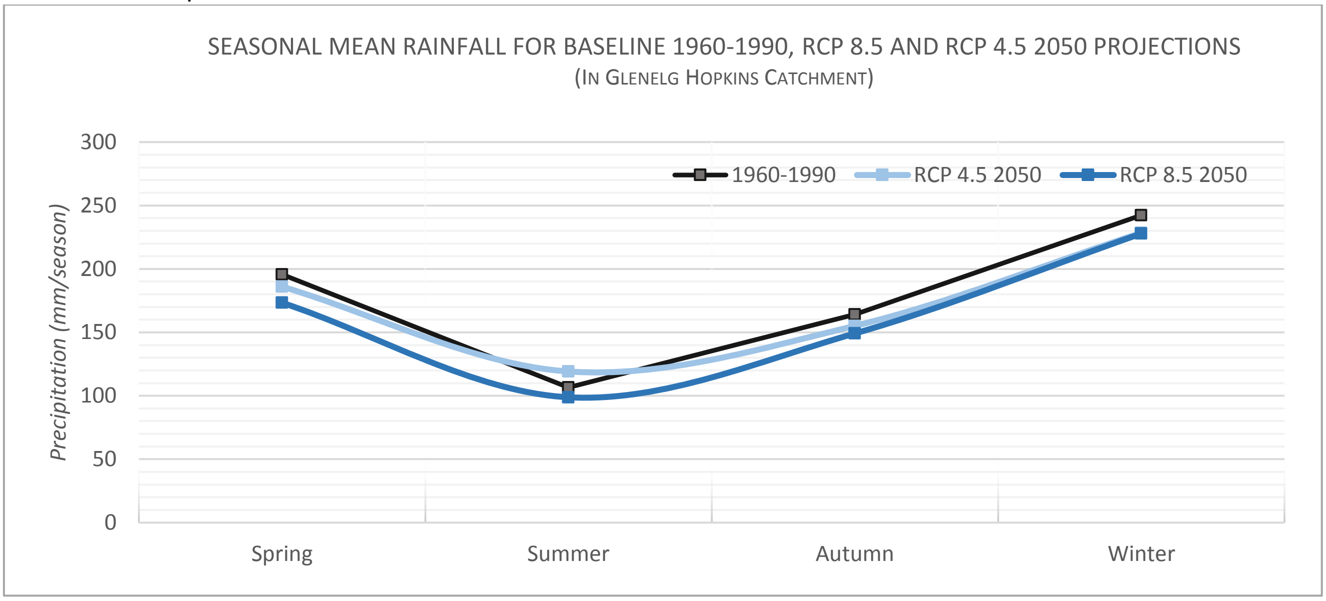

Figure 1 - Seasonal Mean Rainfall for baseline, RCP 4.5 and RCP 8.5 2050

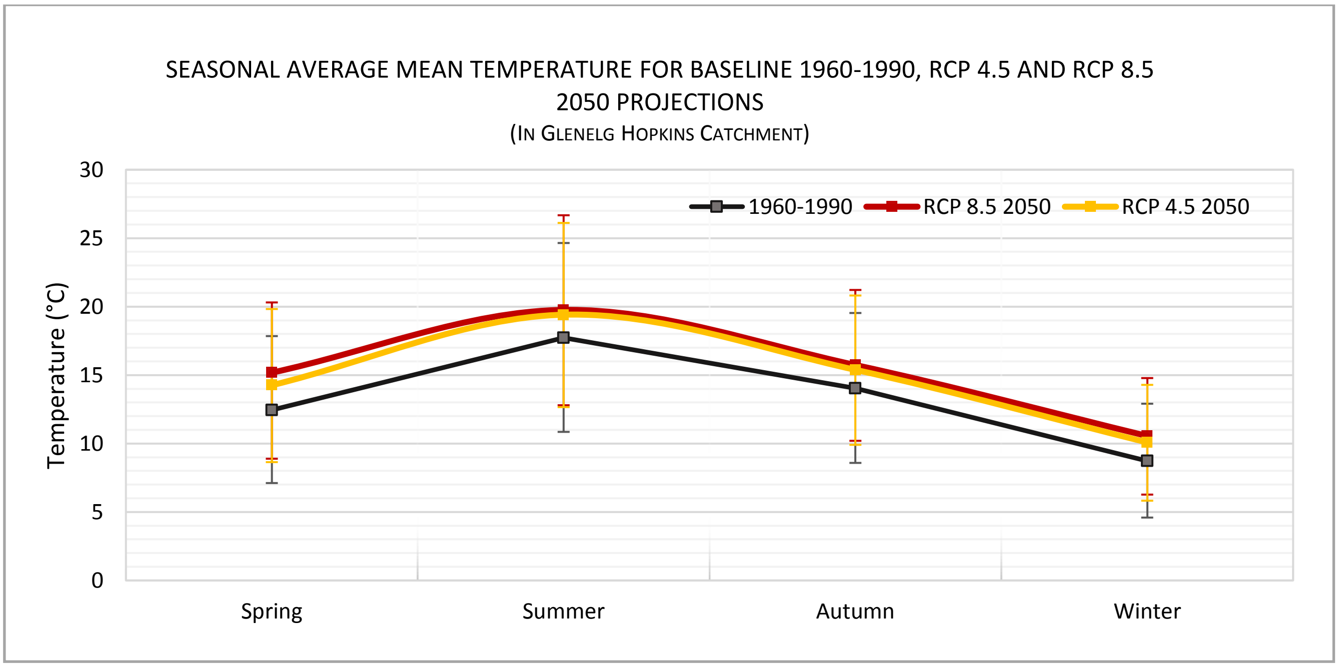

Figure 2 - Seasonal average of mean temperature for baseline, RCP 4.5 and RCP 8.5 2050 (with deviation bars showing average maximum and minimum temperatures for particular season)

Projected values indicate decrease in rainfall and increase in temperature, with the most prominent changes in both extremes of maximum and minimum temperature. The resulting climate shift in the region is milder than in the rest of Victoria, but presents Glenelg Hopkins catchment with opportunities to diversify its land-use by adding pastures more suited for warmer climates into its agricultural production. It also calls for an improvement of water management and water allocation methods in parts of the catchment. Maps demonstrating the projected change in annual rainfall and mean temperature can be found in Figure 3 and Figure 4.

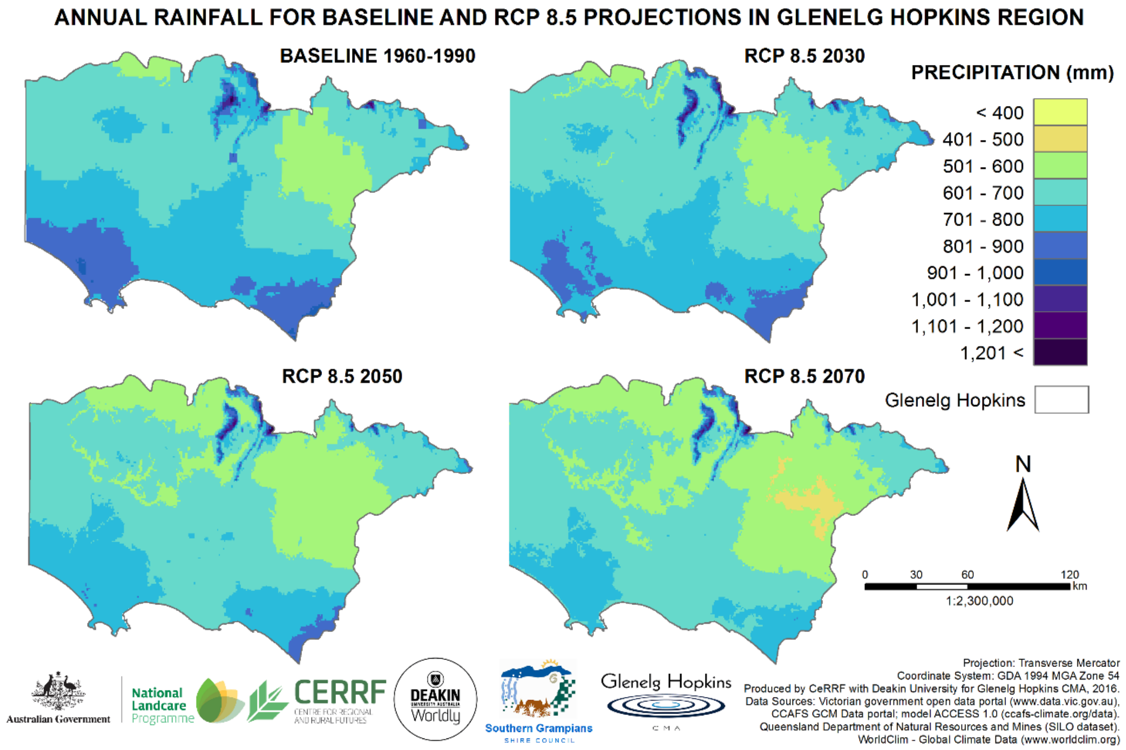

Figure 3 - Mean annual rainfall for baseline 1960-1990 and RCP 8.5 projections

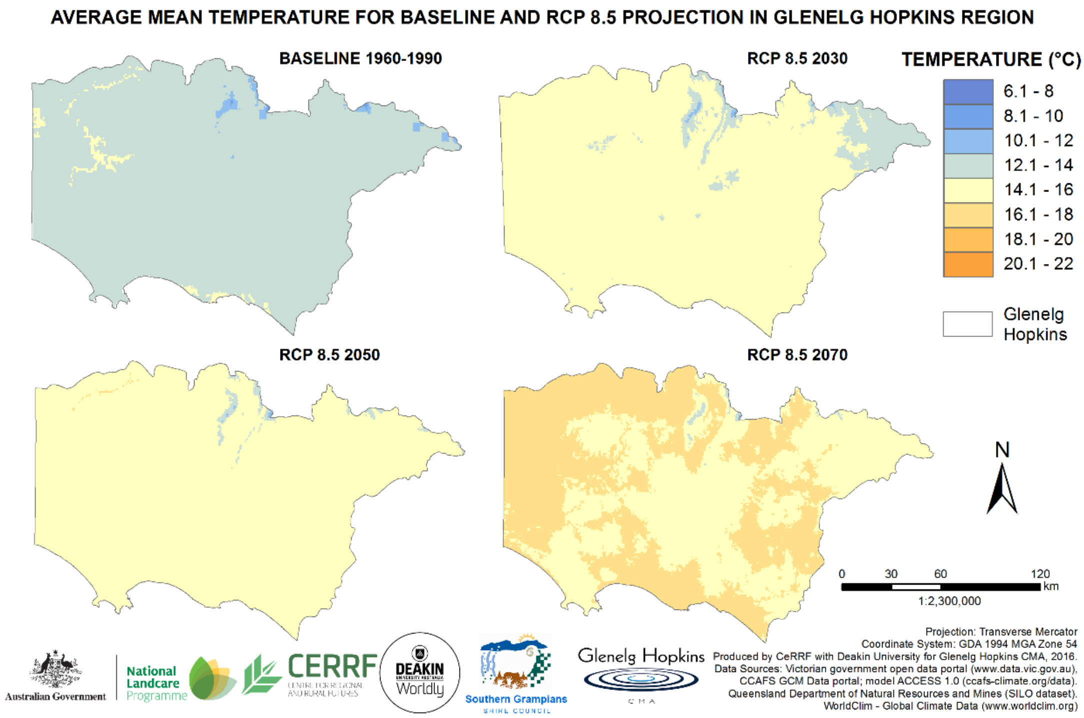

Figure 4 - Annual Mean Temperature for baseline 1960-1990 and RCP 8.5 projections

9. Methodology

In order to generate the specific long-term data, information and strategic plans to adapt to climate change, a simplified model of the approach is diagrammatically depicted in Figure 5 was applied in this study. The overall methodological approach used to assess the degree of land-use suitability, in both a current and future climate, integrates a Multi Criteria Analysis (MCA) applied with an Analytical Hierarchy Process (AHP) in a Geographic Information System (GIS), to spatially represent land-use suitability. The methodology is informed, and takes place within, the policy context established by the relevant government policy statements at national, state and regional levels.

The MCA is implemented using an AHP (Saaty, 1980, Saaty, 1995, Saaty, 1994). Broadly defined, for the study region, biophysical variables (criteria) that determine the growth and production of the selected agricultural commodity, are arranged into a hierarchical order, this forms a decision making structure that can be evaluated (an example of such hierarchy can be found in Appendix I). Criteria are then assigned numerical values (weights), which are determined primarily from expert knowledge and judgement. These weights are placed on each criterion and indicate the relative importance to one another and to the overall output. MCA has been used extensively around the world in many studies based on land-use suitability, where a primary focus is combining biophysical data with expert knowledge to formulate a single suitability index class (Jankowski and Richard, 1994, Hossain et al., 2006).The first module in the methodological approach are historical climatic inputs and future climate change projections as derived from the global IPCC Assessment Reports (IPCC, 2007a, IPCC, 2013). In particular, future climate projections are based on the CSIRO ACCESS1.0 Global Climate Model (GCM) (Ramirez & Jarvis 2008) at the spatial resolution of 1 km^2 using emissions scenarios created from the Representative Concentration Pathways RCP (CSIRO and Bureau of Meteorology 2015; van Epersele 2014). This model uses the Intergovernmental Panel Climate Change (IPCC) scenarios employed in the IPCC Fifth Assessment Report (AR5). These are scaled down to a regional level for each of the key climatic variables. As shown in the figure, several other data inputs, in addition to climate, are necessary; these can include, but are not solely limited to, soils and landscape. In all, the combination of these three main inputs can be used to describe the primary growth requirements of common pasture species.

Climatic conditions are key metrics for modelling plant growth, either by restricting ecological process (e.g., plant establishment and growth rate), or by limiting management activities such as the timing of specific farm practices (e.g., ploughing, sowing or harvesting). These climatic metrics are a significant link between prevailing climatic conditions, as measured at weather stations, and their specific relevance to land use activities. A change in climatic conditions implies new opportunities for, or risks to, land use (Stone and Meinke, 2006). Therefore, exploration of climate change impacts on land suitability can identify areas where the range of options is changing or may be expected to change in the future, and whether the inherent biophysical flexibility in land-use options is increasing or decreasing. This information can then provide the platform from which to explore the socio-economic implications of climate change alongside other drivers of change (Brown et al., 2008).

The AHP allows for experts' participation in the decision making process. Compared to empirical models this expert systems model incorporates the knowledge of experts who have an in-depth understanding of one aspect of the specific system of concern. This is seen as an essential step in suitability analysis because expert based knowledge can fill gaps created by poor empirical based knowledge or poor data quality. With the contribution of regional experts in agronomy, soil science and farming (amongst others), an AHP model is constructed for each particular commodity.

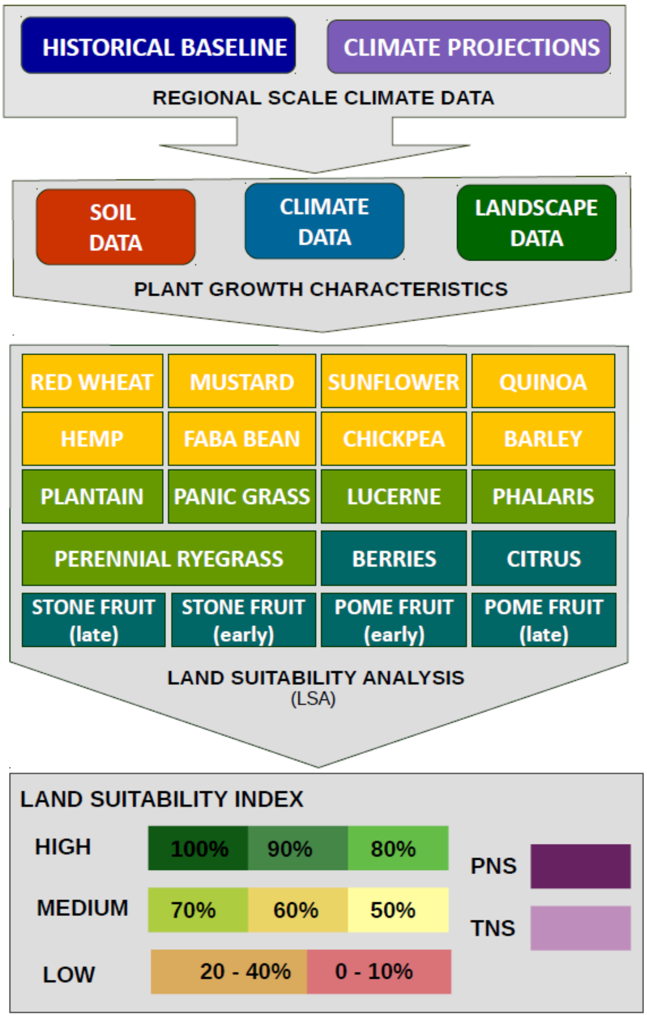

Figure 5 – LSA methodology

9.1 Suitability Analysis

The methodological approach adopted in this project includes at its core *Biophysical Land Suitability Analysis* (LSA) for the agricultural commodities of interest, which is focused at the regional level. Biophysical LSA is defined as the process of determining the fitness, or the appropriateness, of a given area of land for a specified use (FAO, 1976); see also (McHarg, 1969, Hopkins, 1977). Biophysical LSA can provide a rational basis to identify the most favourable utilisation of land resources and land use planning (FAO, 1993). It examines the degree of land suitability for the growth (cultivation or cropping) of the agricultural commodity of interest. It has thus gained wide acceptance and adoption across a wide range of users including land managers, agriculturalists and planners.

Modifications in agricultural land suitability caused by climate change can be assessed by comparing future suitability maps (using climate change projections) with current suitability maps (using historical/present climatic conditions). Overall this can provide an assessment of the potential climate change impacts on agricultural systems, be utilised as a decision support tool and facilitate discussions of the policy options to respond to the likely impacts.

Further comprehensive explanations of the Biophysical LSA methodology can be seen in the publications of *Geography Compass* (Sposito et al., 2010a), *Applied Spatial Analysis* (Pelizaro et al., 2010), *Applied GIS* (Sposito et al., 2009) and *Open Journal of Applied Sciences* (Sposito et al., 2013) to which the reader is referred. In this report, only a brief explanation of the approach is provided with an emphasis on the development and application of the LSA models to pasture systems.

9.2 Suitability Framework

The United Nations Food and Agricultural Organisation (FAO) have an established framework structure for the assessment of suitability for any type of land use and land cover (FAO, 1976). This structure is hierarchical in design and comprises of Orders, Classes, Subclasses and Units. Suitability Orders indicate if a unit of land is Suitable (S) or Not Suitable (NS), hence there are two suitability orders. Suitability Classes are used to reflect degrees of suitability, for example, at base three classes can be defined; High (80% - 100%), Moderate (50% - 70%) and Low Suitability (0% - 40%). Furthermore, the Not Suitable order can be defined into two classes; Temporarily Not Suitable and Permanently Not Suitable. This framework has been modified slightly for use in the Glenelg Hopkins study. The core of the framework is maintained for application in the study region. The two principle suitability orders are maintained; S and NS. NS is further defined into Permanently Not Suitable (PNS) for areas excluded based on factors that cannot be changed by farm management practices (ex. soil depth) and Temporarily Not Suitable (TNS) for areas with currently unsuitable factors that can be made favourable by management practices (such as application of lime on acidic soils).

9.3 Caveats

The LSA models are validated using regional expertise and input by local growers and experts. However, it is important to be aware of a number of caveats when interpreting the results of the models:

1. The methodology has been formulated for application at regional and local levels. In particular, LSA maps are developed and presented at a regional level with a spatial resolution of 1 km^2, which is the resolution of the downscaled climate change projections. Therefore, *LSA maps should not be used to infer (current and future) conditions at a site level (e.g. at farm level).*

2. LSA maps depicting future conditions substantially depend on the input climate change projection data, which are inherently uncertain. A multiplicity of futures is possible depending on major policy decisions over time and how the climate system will respond to them. Therefore*, future LSA maps depict a likely future projected by the IPCC and, by no means, the only future.*

3. The modelling approach does not account for some important components of pasture production; for instance, the effect that changing climatic conditions may have on bees and pollination, or on plant disease status. It also does not consider management practices that also significantly influence pasture growth. Therefore, *LSA maps depict strictly biophysical conditions that are based on currently available reginal-scale data.*

4. With the projected regional increase in temperature and associated decline in rainfall, extreme weather events, (including fire risk) are likely to increase across the study region. This is not considered in the present study and will require complementary research and (possibly) the preparation of overlay maps showing areas of greater risks.

5. Each commodity's biophysical requirements for climate, soil and landscape – were identified by a review of the scientific literature and their value ranges were validated using expert opinion and regional expertise. It is nonetheless possible for some subjective information, via the expert opinion phase of the exercise, to influence the model design or the weighting of individual criteria within the models, especially in the case of emerging commodities that have not been grown on a large scale in the region.

6. The spatial soil data available for the LSA modelling is limited to the data availability. Region specific issues such as aluminium toxicity could not be included in the model since there are not available in a spatial format. Waterlogging susceptibility layer supplied by the Glenelg Hopkins CMA has been included in the model, although, management practices improving drainage such as raised beds or liming to decrease soil acidity, could not be incorporated.

7. The study did not examine different varieties within a particular agricultural commodity. Considerable variation can occur between varieties within a species with respect to their biophysical requirements. Grazing management is also a significant factor influencing establishment rates as well as persistence.

8. This study contains a number of commodities that are either grown on a small commercial scale limited to a certain area of the catchment or not at all (such as quinoa, hemp, Citrus, panic grass etc.). The lack of growers in the region

made it harder to validate such models. They are predominantly reliant on scientific literature and expert opinion of agronomists and farmers growing similar pasture species, and will be amended once more trials are available from the region.

9. It is difficult to account for the contribution that a grower's management practices can make to the suitability of a specific commodity at a particular geographical location. It is hence entirely possible for a particular grower to achieve good pasture growth and persistence at a location that has been modelled as having a low biophysical suitability and, conversely for a grower to achieve poor yields at a location that is ranked with a high biophysical suitability. It should also be noted that the models do not take into account other factors that may *impact* on suitability and yield, such as extreme climate events, pests and diseases, or socio-economic considerations.

10. The report has looked at a selection of agricultural commodities across the Glenelg Hopkins catchment. The reader should therefore be aware that the designation of an area in the region as less suitable in future climates only applies to the particular commodities modelled in this report, and that those same areas may become more suitable for other pastures. Additional modelling will be required to examine other agricultural commodities in order to have a more comprehensive understanding of the agricultural potential of the Study Region, now and in the future.

10. Biophysical Data Inputs

10.1 Observed Climate

Past and current climate data was obtained through the SILO Project (Jeffrey et al., 2001), which is hosted by the Science Delivery Division of the Queensland Department of Science, Information Technology, Innovation and the Arts (DSITIA). SILO is based on Bureau of Meteorology (BoM) climate data and includes multiple datasets of variables such as temperature and rainfall. The data is Victoria-wide and is available at a resolution of 5 km^2 (grid). In order to increase coastal coverage and get a finer resolution data of 1 km^2, the SILO data has been averaged with WorldClim data, as mentioned in Chapter 0 on climate change.

Interpolation techniques (thin plate smoothing splines for climatic variables and ordinary kriging for rainfall) are used on weather observation station climate information supplied by the BoM (Jeffrey et al., 2001). There are several points where uncertainty can affect data quality, such as the physical weather observation stations themselves. Data can be lost at these points due to instrument failure, non-reporting of data or incorrect recordings. In the interpolation of climate data, there is also an associated level of error, given values are being estimated between two points. The associated levels of error in the SILO and WorldClim climate datasets, and how these are handled, are explored and quantified in Jeffrey et al., (2001).

Commonly used in climate studies is the 'climate normal', which is used as a reference period for comparative purposes between current, historical and future climates. Generally, they are calculated over a standard period of thirty years, which is long enough to include year to year variations but not that long to allow it to be influenced by long term climate trends. The World Meteorological Organisation (WMO) uses the period of 1961 to 1990, which is also used in Australian meteorological references. WorldClim data set uses period of 1960 to 1990. This study has used the 1960-1990 climate normal period as a baseline comparison against future climate projections and simulated suitability analyses. The climate normal, hereafter, will be referred to as the 'baseline' climate.

10.2 Future Climate

Future climate scenarios were created using the CSIRO's Global Circulation Model (GCM) CSIRO-ACCESS1.0 model (Ramirez & Jarvis 2008) and RCP 4.5 and 8.5 emissions scenario (van Epersele 2014; CSIRO and Bureau of Meteorology 2015). The 4.5 (low emissions) and 8.5 (high emissions) scenarios are one of the scenarios used in GCM models and climate change analysis. Projections are based on assumptions about future demographic, economic, land use, and science and technological changes and are reported on in the IPCC Representative Concentrations Pathways (van Epersele 2014).

10.3 Landscape

A Victoria wide Digital Elevation Model (DEM) provided the basis for landscape analysis. This is in a raster grid format, with a grid cell resolution of 100m^2. This dataset represents the ground surface topography or terrain of Victoria. The dataset allowed the calculation of critical geographic features such as slope, altitude and aspect. The DEM has been sourced from NASA's Shuttle Radar Topography Mission (SRTM) landscape dataset (NASA and USGS, 2014), which is supplied at 1 arc second (equivalent to a 30 metre resolution). This is hosted in conjunction with the United States Geological Survey (USGS).

10.4 Soils

Soil type (Isbell and CSIRO., 2002) is one of the most important factors that influences land utilisation. It provides the physical, chemical and biological activity basis required for plant growth. Principal information for soils data for this study has been sourced from Soils and Landform Mapping, undertaken by the Victorian State Government found on the Victorian Resources Online (VRO) web-based platform (Victorian State Government, 2015b) or the Victorian Data Portal, data.vic.gov.au (Victorian State Government, 2015a). These studies are at a geographic scale of primarily 1:100,000 and these surveys and maps provide a description of the land and associated soil types/units. Finer scale mapping can be more accurate, but the available data at all scales across the Glenelg Hopkins catchment is sufficient for suitability modelling. Further information for soils data and attributes have been sourced from the Soil and Landscape Grid of Australia, produced by the CSIRO (CSIRO and TERN, 2015) and from the soil layers supplied by the CMA (containing waterlogging, salinity, erosion and other susceptibility maps).

Soil attributes, as used in land-use suitability modelling, can be categorised into two broad groupings; physical attributes and chemical attributes. Physical attributes relate to the actual physical properties of the soil and include measures such as texture or soil horizon depth. Measurements for these are usually done in the field at a soil pit. Chemical attributes relate to the chemical composition of the soil and can include measures such as soil nutrient composition or soil pH. Measurements for these are usually done in a soils laboratory on collected field samples. The attributes that are used within the AHP are listed in Table 1.

Table 1 – Soil attributes included in the LSA models

Soil Grouping	soil attribute
Physical	Texture, Drainage, Useable Depth (2/3 of Horizons A & B), Depth to Bedrock, Coarse Fragments, Waterlogging Susceptibility, Stoniness
Chemical	Soil pH in water & $CaCl_2$, Salinity/Electrical Conductivity (ECe), Sodicity

11. Validation

The AHP, at its core, is an expert's system model, in that much of the decision points in an AHP are derived from expert based knowledge. This can range from the weightings placed on each hierarchy level to the growth indices used to formulate suitability index class values. This expert input is an essential step in LSA because it fills information gap due to poor empirical based knowledge or poor data quality, and also ensures the outputs are more locally-relevant. As such, the expert input that is used to formulate an AHP land-use suitability model is used to validate the output.

Initial AHP land-use suitability models were formulated based on previously-developed LSA models for different regions of Victoria. These were adapted and adjusted for use in the Glenelg Hopkins catchment through a thorough literature review, and run to produce a preliminary output map of suitability. The initial maps, for the baseline climate, were then reviewed by local 'experts' (farmers, farming groups, agronomists, plant breeders, among others) at a wide cross-section of locations around the catchment. Based on experts' knowledge of the region, any inconsistencies in the predicted suitability were identified and the model amended accordingly by making adjustments to weights and ratings. As a matter of course, this validation process is repeated until there is a general satisfaction with the map output. In this particular study, the validation input on whether the initial 'preliminary' map reflected their understanding of the region's suitability for the selected commodities has been quite diverse. It largely depended on the location and primary land use therein. The Hamilton Highway has often been referenced as a suitability demarcation for perennial ryegrass. Validation feedback often mentioned decrease in persistence of perennial ryegrass in southern high-rainfall areas traditionally used as dairy farms. In contrast, the area under more resilient phalaris has been increasing. The validation process was followed for each of the AHP land-use suitability models, as used in this project. Suggested changes to the models were made and are emphasised in latter parts of this report, specific to each commodity.

In general, changes have been made to match the regional pasture growth curve (as recorded from EverGraze trials in 2013), differentiating between winter and summer active pasture species. Perennial ryegrass and phalaris have been added to the commodity list as reference species, allowing farmers to compare novel species with currently prevalent pasture systems. Less abundant commodities (plantain, panic grass and lucerne) received a rather mixed feedback of both successes and failures. More trials are therefore needed, but as mentioned by a number of farmers, high seed prices and the ever-unpredictable changes in seasonal climate conditions, limit their willingness to experiment. All other assumptions made are detailed at the pertinent commodity-specific sections of this report.

A waterlogging susceptibility data supplied by the CMA has also been imbedded within this project's models of species such as lucerne that are intolerant to waterlogging. A regional issue of aluminium toxicity hindering plant development has been pointed out on numerous occasions in both crop and pasture validation sessions. A spatial dataset containing specific catchment-wide aluminium levels is not available. The models are therefore using the values of pH and soil textures as an indication of potential aluminium toxicity issue.

12. Pasture Production

Majority of the catchment has been traditionally dominated by dryland pasture systems based on winter active varieties of perennial ryegrass or phalaris with subterranean clover (Morant & Miller 2016). Establishment and less demanding grazing management of the conventional ryegrass cultivars are the greatest advantage of winter active perennial ryegrass cultivars, although, increasingly prevalent hotter summers cause a significant decline in its persistence. Use of new ryegrass cultivars, or more drought persistent phalaris, is therefore needed to sustain current production levels. There is also an increasing trend of using summer active pasture species to cover feed requirements of stock during the warm season, instead of heavily relying on silage. Figure 6 shows the standard pasture growth curve of winter active species traditionally grown in the region, as demonstrated at the EverGraze Hamilton trial site in 2016 (Behrendt R, Morant A, Clark S, McCaskill M, Raeside M, Ward G, Cameron F 2013). The introduction of summer active species is likely to complement existing pasture management systems. Although summer crops and lucerne have the potential to provide out of season feed, progressively shorter springs with insufficient rainfall increase the risk of pasture or crop failure (Cloven Hills Est. 2014).

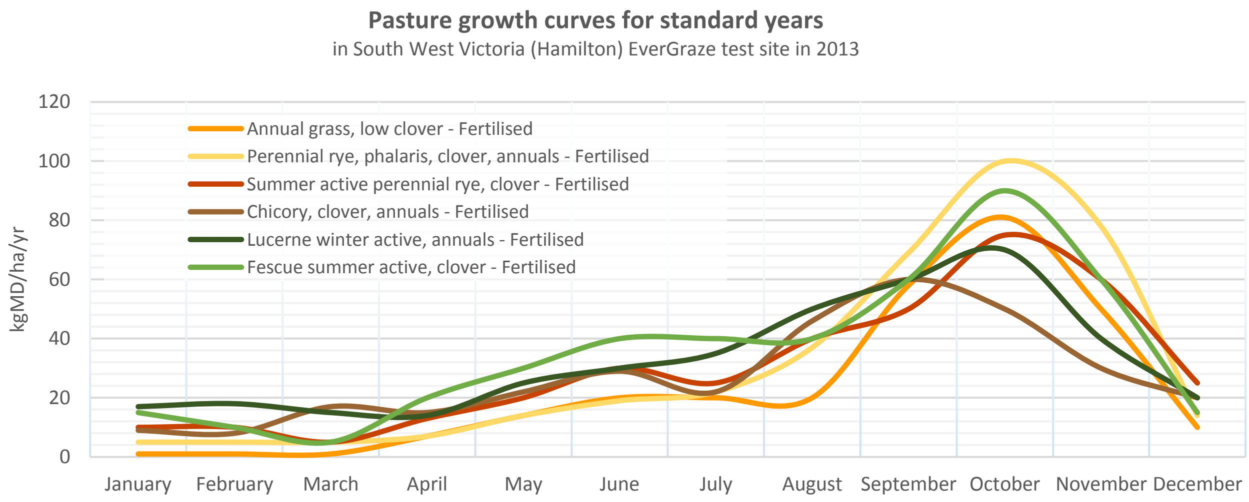

Figure 6 – Standard year pasture growth curves for different pasture species in Hamilton EverGraze trial site in 2013 (Source: EverGraze, 2013)

Factors affecting pasture growth are (PGG Wrightson Seeds 2016c; DairyNZ 2008):

- PASTURE COVER: pasture growth rates are low if pasture cover is very high or very low
- TEMPERATURES: pasture growth is limited if ambient temperature is too low or too high (ideal temperature range differs for each species but also between varieties of the same pasture species)
- MOISTURE: pasture growth rate is reduced if available soil moisture is insufficient, but also if excessive rainfall and soil parameters cause waterlogging
- NUTRIENTS: pasture growth decreases with dropping nutrient levels
- PLANT DAMAGE: pasture growth rates are low due to insect infestation or overgrazing

The climate projections used in our models predict a slight increase in annual production of perennial ryegrass and white clover pasture mix, which is likely to be reversed to a decline by 2070 caused by stimulation of winter and early spring pasture growth rates by higher temperatures, but counteracted by shorter springs (Eckard R. & Cullen B. 2008). The feedback received during validation suggests a recent trend of cropping to extend south, creating mixed pasture and cropping management systems or replacing pasture based farming altogether. Consistent with those observations, the projected changes in climate are very likely to cause a shift of agroecological zones (found in Appendix II) southward.

A. Grasses

Perennial Ryegrass (winter active)

Scientific name: *Lolium perenne*
Common name: Perennial Ryegrass
Baseline varieties: Nui

Perennial ryegrass is a long-lived, densely tillered tufted grass native to regions with a temperate climate, and used for both pasture and turf in Australia (State of Victoria DPI: Office of the Gene Technology Regulator 2008). Its traditional cultivars (such as Victorian) have been widely used across the southern parts of the region due to its ease of management that tolerates different grazing practices, and high nutritive value (Morant A & Sargeant K 2013). The fastest growth of grass leaves appears in spring (every 7 days) and slows down in the winter (every 30 days) as demonstrated in Figure 7. Ryegrass tillers always have only 3 live leaves that die after 21 days in spring and 90 days in winter (DairyNZ 2008). The disadvantages of perennial ryegrass are its shallow root system, spring dominant growth pattern with low summer productivity, and poor persistence in hot and dry summers (Morant A & Sargeant K 2013).

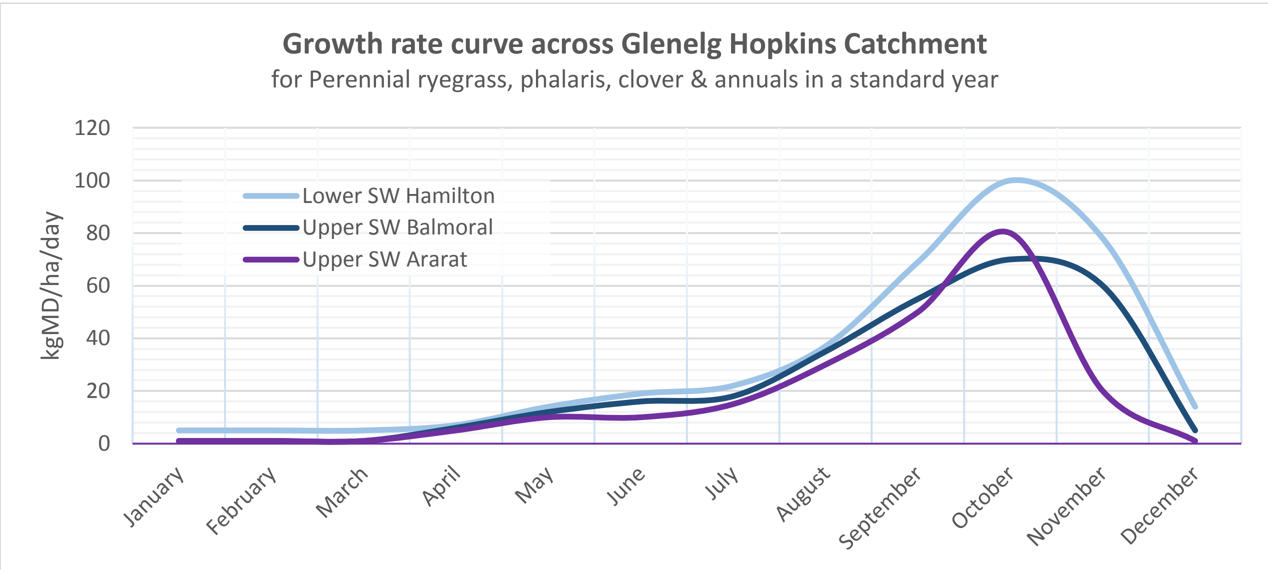

Figure 7 – Standard year ryegrass & phalaris pasture mix growth curves on multiple Evergraze trial sites across Glenelg Hopkins Region (source: EverGraze, 2013)

Validation input stressed the significant differences in persistence between all available cultivars and its susceptibility to hot and dry summers negatively affecting the pasture persistence. LSA model of perennial ryegrass was based on the NUI cultivar with 0 heading days and target yield of 6-8 t/ha. Ideal temperature range is 5°C - 18°C (DairyNZ 2008), minimum rainfall of 600 mm/year (Smith 2012b). Frost has little effect on perennial ryegrass, but prolonged periods of hot and dry conditions lead to reduced persistence (PGG Wrightson Seeds 2016c). Poor nutrient content in soils limits pasture growth, but perennial ryegrass tolerates waterlogging as well as limited levels of elevated soil salinity and acidity. The ideal pH_{Ca} range is between 5.6 – 7.0 (Smith 2012b). The model outputs can be found in Figure 8 as a set of land suitability maps and as a graph with suitability area change in Figure 9.

The projected increase of mean temperature and decrease in rainfall during the pasture's active period is likely to significantly lower the land suitability of perennial ryegrass. Baseline suitability determined by the LSA model is 72.9% but drops significantly, to 60.2% by 2070, limiting the growth of perennial ryegrass to high rainfall, coastal areas. As mentioned above, successful pasture growth and its persistence differs greatly between cultivars and could not be accounted for by the model.

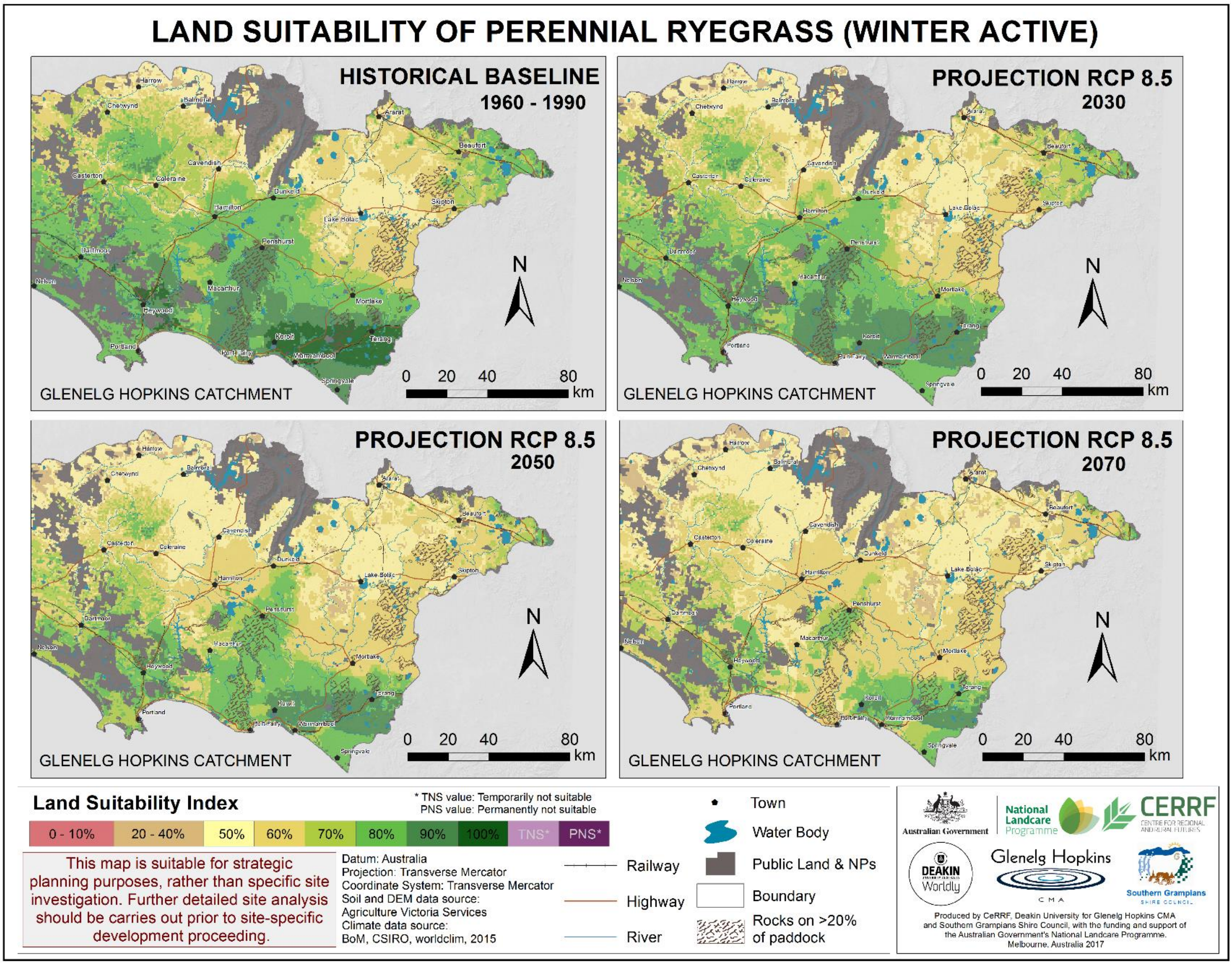

Figure 8 – Land suitability maps of winter active perennial ryegrass in Glenelg Hopkins region

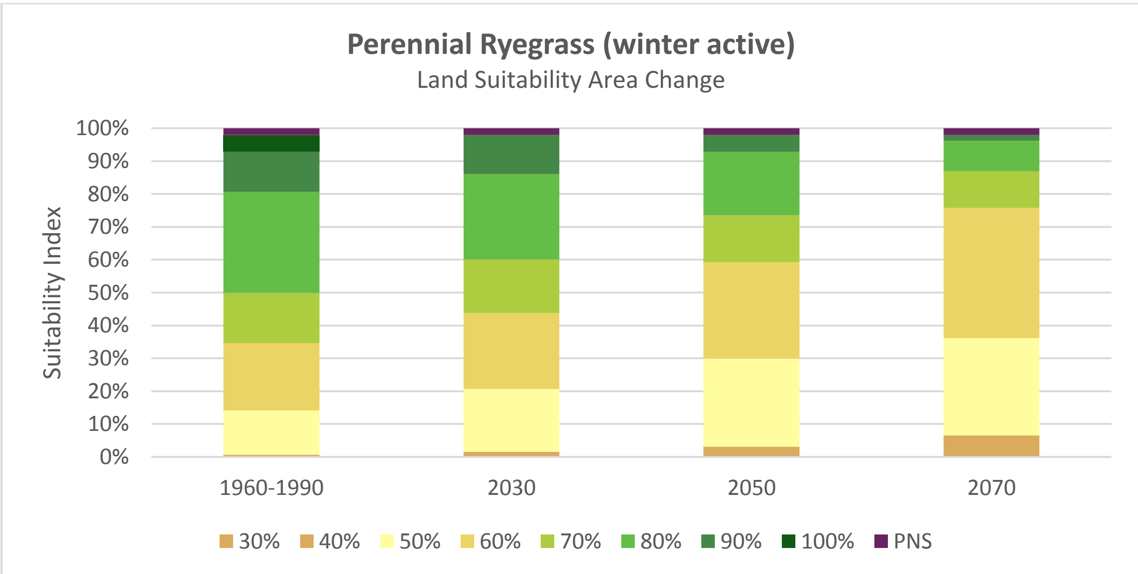

Figure 9 – Land suitability area change of winter active perennial ryegrass

Phalaris (winter active)

Scientific name: *Phalaris aquatica*
Common name: Canary Grass, Harding Grass
Baseline varieties: Holdfast

Phalaris is a temperate perennial grass with good persistence in areas of high rainfall, heavy soils, low aluminium content and medium to high fertility (EverGraze 2008; Clements et al. 2003). Frost resistance, drought and heavy grazing tolerance, ease of establishment, good recovery and fast response to autumn rainfall, high productivity, high competitiveness with weeds as well as tolerance to waterlogging and moderate salinity are the main advantages of phalaris (with certain variability between cultivars)(Watson et al. 2000; Knox et al. 2006). The disadvantages are susceptibility to competition from annual grasses during establishment, risk of phalaris poisoning, low responsiveness to summer rainfall and its sensitivity to acidic soils (Watson et al. 2000; Clements et al. 2003; Knox et al. 2006). Although phalaris can persist under a variety of grazing management practices, its ability to outcompete legumes can cause a decline in pasture quality and production, stressing the need to maintain grass-legume balance (Watson et al. 2000). As depicted in **Error! Reference source not found.**, the pasture growth curve of traditional phalaris cultivars is consistent with that of perennial ryegrass, with highest growth in autumn to late spring and summer dormancy (Clements et al. 2003; Behrendt R, Morant A, Clark S, McCaskill M, Raeside M, Ward G, Cameron F 2013). Varieties such as Holdfast and Sirosa are also winter active but have low to moderate summer dormancy (Watson et al. 2000; PGG Wrightson Seeds 2016a).

Average annual rainfall required by phalaris is between 550 and 600 mm (Watson et al. 2000), with the minimum being 400 mm/year (Knox et al. 2006). Ideal temperature for pasture growth is between 15°C and 25°C (Watson et al. 2000). Phalaris can grow on a wide range of soils but performs well on deep, heavy textured soils of high fertility and low acidity (ideal pH_{Ca} 5.8-7.5, with areas with $pH_{Ca} < 4.0$ being temporarily not suitable due to increased potential of aluminium toxicity)(Knox et al. 2006; Watson et al. 2000). Validation stressed the issue of soil acidity and higher persistence in the north of the catchment.

The modelled decrease in winter rainfall and increase in mean temperature is likely to increase the suitability of phalaris further south to areas traditionally dominated by ryegrass, but slight decrease to 80% suitability in the north-east of the region by 2070 (as shown in Figure 10). Figure 11 indicates an increase in median suitability of the catchment to grow phalaris from 76.1% in 1960-1990 to 81.9% in 2070. Phalaris is projected to have the highest increase in suitability out of the 5 selected pasture commodities.

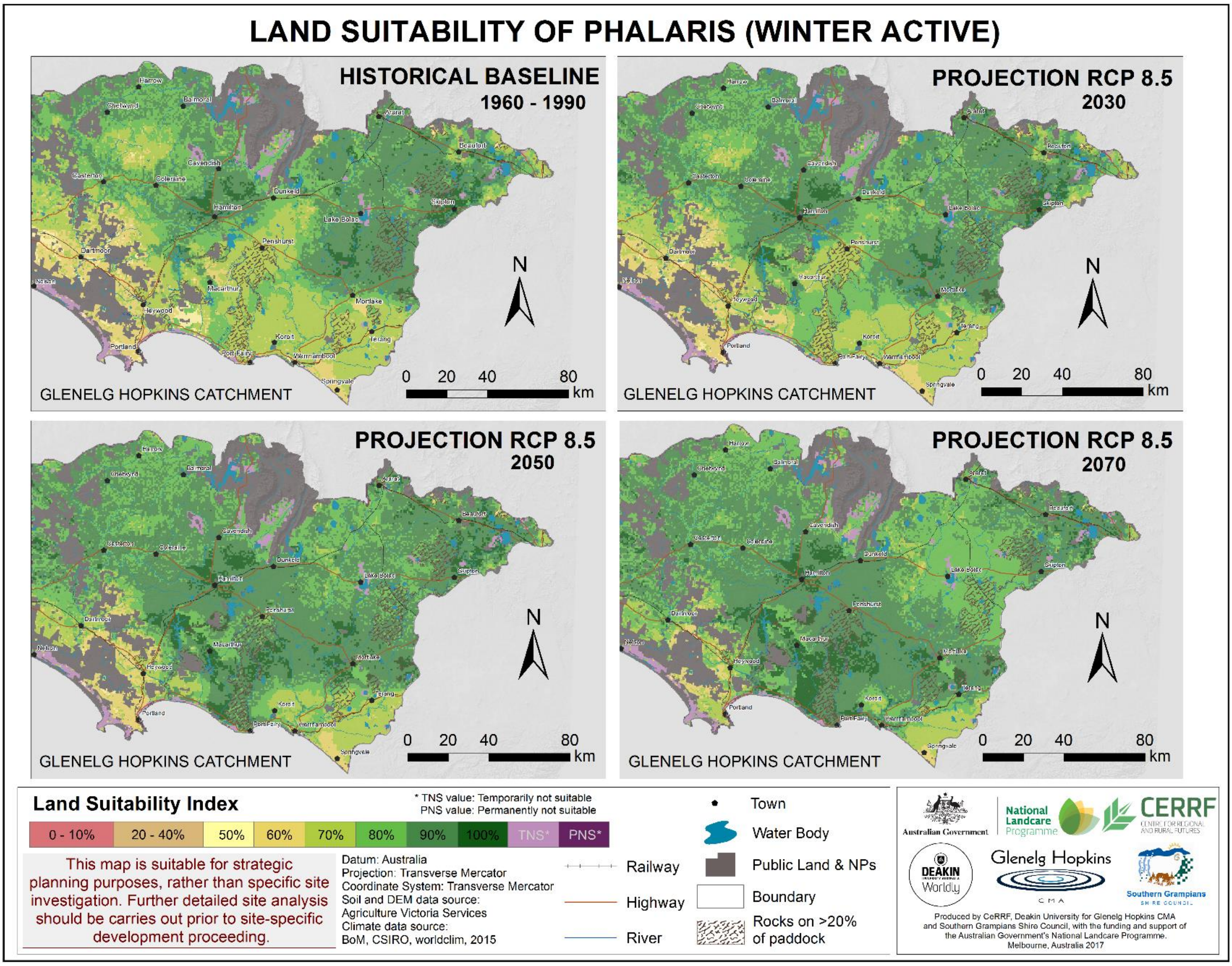

Figure 10 – Land suitability maps of winter active phalaris in Glenelg Hopkins region

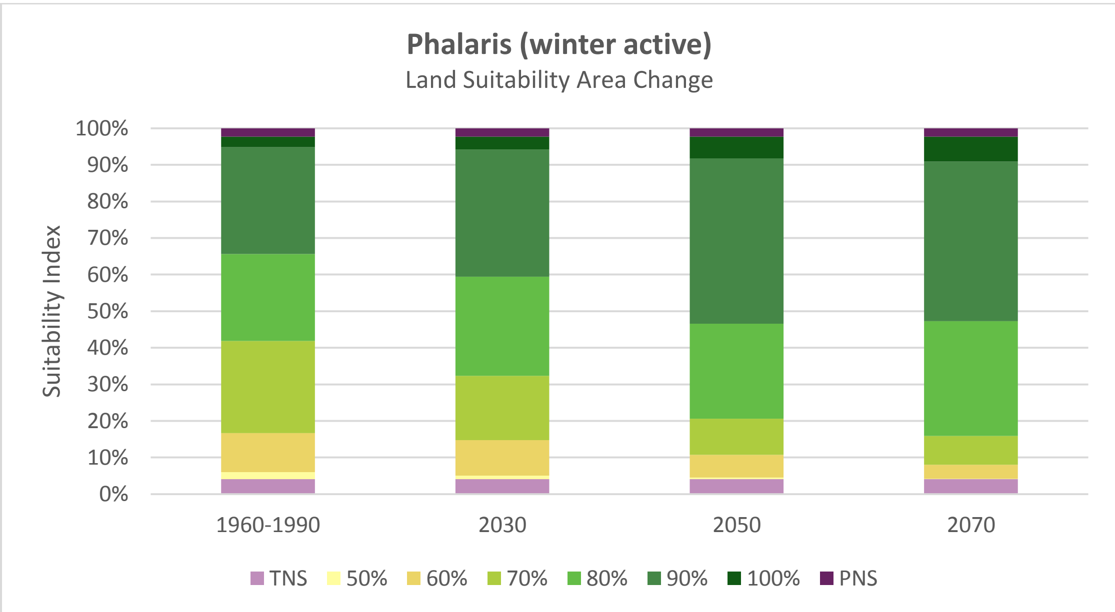

Figure 11 – Land suitability area change of winter active phalaris

Panic Grass (summer active)

Scientific name: *Megathyrsus maximum*
Common name: Green Panic, Guinea grass
Baseline varieties: Green panic

Panic grass is a tufted, tall, C4, summer-growing perennial, producing feed over spring, summer and autumn (FAO 2016; Mcdonald 2003). Its quick response to summer rainfall make it superior to many other tropical grasses and likely to complement winter dominant, dry-land pasture systems found in Glenelg Hopkins region. As a tropical grass, panic requires higher temperatures to stimulate its growth and is intolerant to frost. Validation predominantly reflected on Green or Gatton panics, stressing the importance of drainage and temperature for successful pasture growth. Green and Gatton panics have poor tolerance to flooding and drought, unlike Bambatsi panic, which has a superior tolerance to flooding and moderate frost tolerance (Mcdonald 2003).

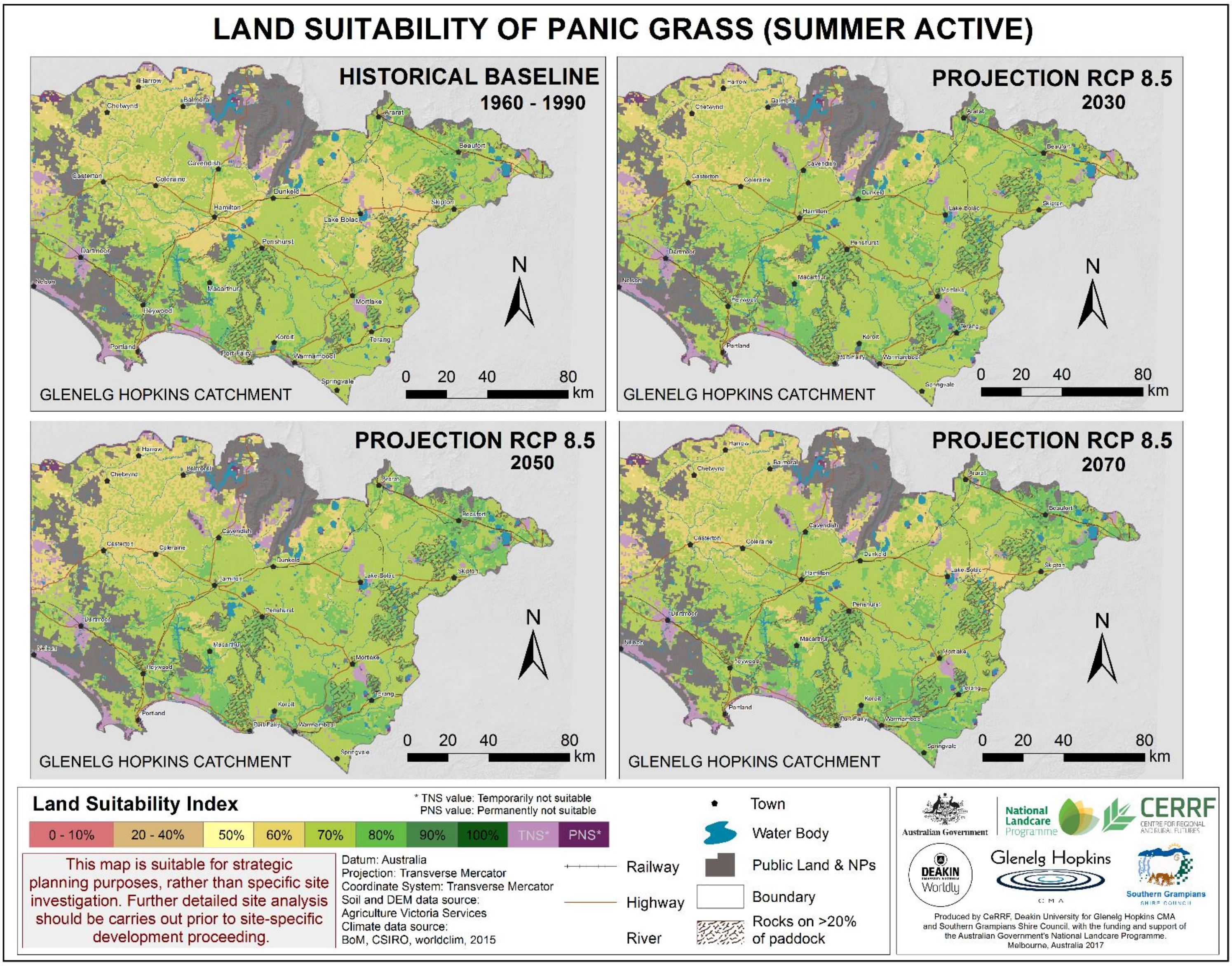

Figure 12 – Land suitability maps of summer active panic grass in Glenelg Hopkins region

Panic grass grows best on cracking clay or loamy soils of medium to high fertility with pH_{Ca} between 5.0 to 8.0 (FAO 2016; Mcdonald 2003). Areas with topsoil pH_{Ca} <5.0 and subsoil pH_{Ca} <4.6 are marked as temporarily not suitable. Bambatsi panic requires a minimum average rainfall of 450 mm/yr, whereas Green and Gatton panics prefer areas with more than 500 mm/yr (Mcdonald 2003). Panic grass is palatable when kept short and once established, it persists well under set stocking (Daur 2016; Mcdonald 2003).

Figure 12 shows the modelled suitability of panic grass in the region, which increases from the baseline 64.9% to 66.5% by 2070. The positive changes are predominantly driven by a projected increase in temperatures as well as summer rainfall events, particularly along the coast. Temperate conditions in the catchment with lower mean temperatures but sufficient summer rainfall in the south, and more favourable, higher temperature but limited summer rainfall in the north, cause panic grass to remain within the medium suitability range (depicted in Figure 13).

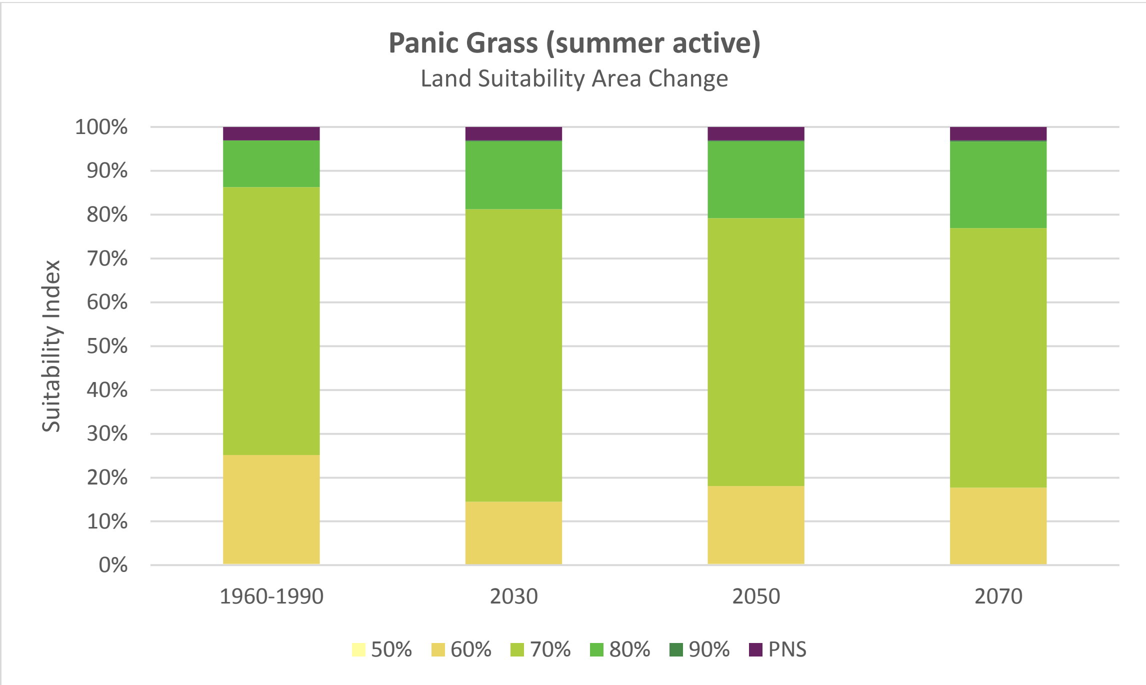

Figure 13 – Land suitability area change of summer active panic grass

B. Herbs

Plantain (winter active)

Scientific name: *Plantago lanceolata*
Common name: Tonic plantain, narrow-leaved plantain
Baseline varieties: Tonic plantain

Plantain is a winter active, tap-rooted, perennial herb of moderate to high feed quality with a high mineral content and dry matter yield (NZ Forage Systems 2011; Judson & Moorhead 2009; Moore 2013; Agricom Ltd 2012 2012). It has a good heat and drought tolerance (but less so than lucerne due to shallower depth of its taproot and high number of fibrous roots in the topsoil) (NZ Forage Systems 2011; Judson & Moorhead 2009). Plantain has excellent dry matter production, especially during the winter. It is highly responsive to autumn and spring rainfall (Judson & Moorhead 2009) with opportunistic summer growth (Moore 2013). Plantain is relatively slow to establish due to low competitiveness with other more vigorous species, it therefore requires careful management in order to persist (NZ Forage Systems 2011). Its advantages are a good pest resistance and low fertility requirements (Knox et al. 2006).

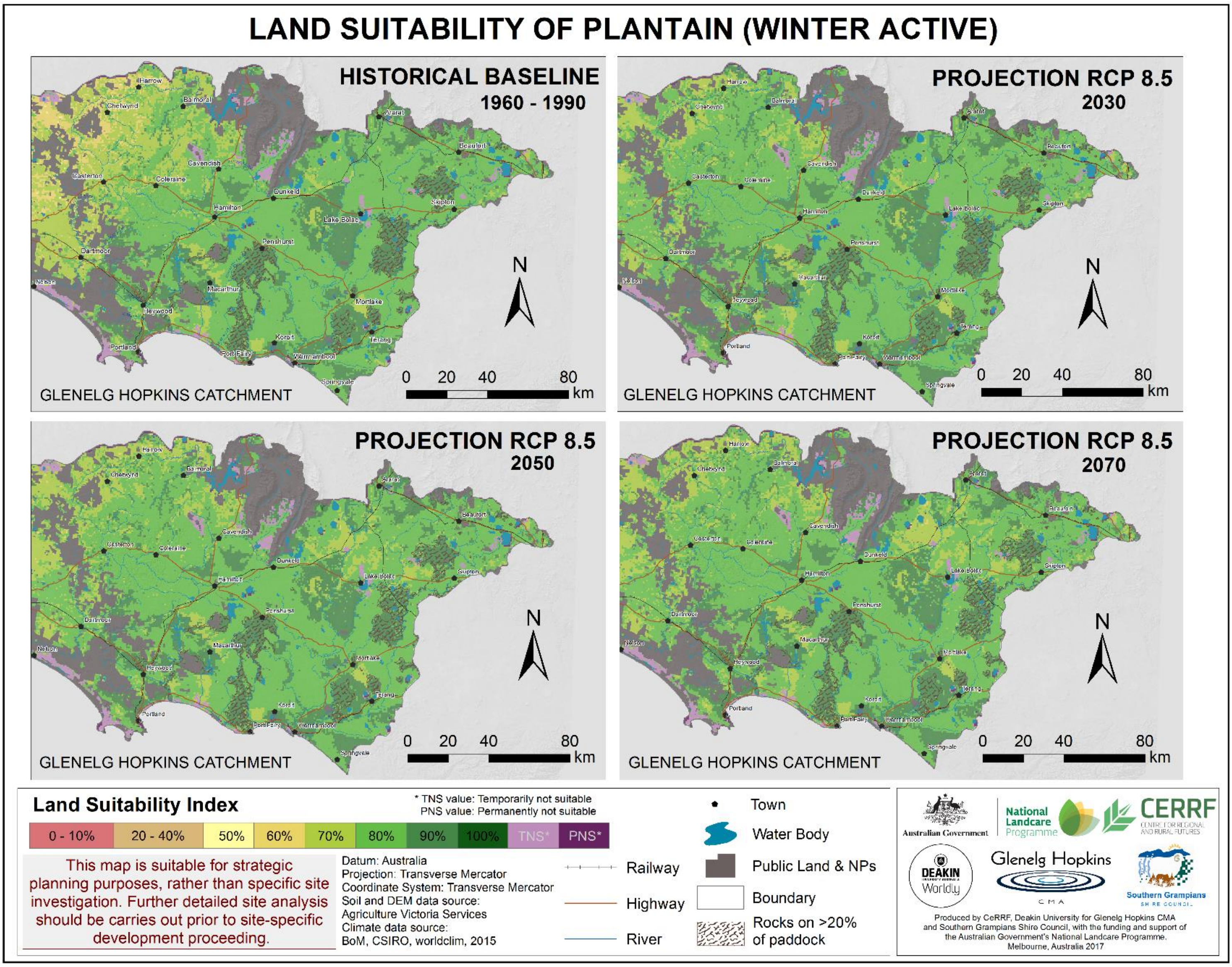

Figure 14 – Land suitability maps of winter active plantain in Glenelg Hopkins region

Plantain requires average annual rainfall above 450 mm and ideal temperatures for growth between 10°C and 25°C (Moore 2013). It can grow on a wide range of soil types apart from deep sands and soils susceptible to waterlogging . It tolerates low fertility and pH_{Ca} between 4.2 – 7.8 (Moore 2013; NZ Forage Systems 2011; Agricom Ltd 2012 2012). Validation feedback stressed the need of sufficient rainfall even during summer months, low tolerance to waterlogging and aluminium toxicity.

Figure 14 shows modelled land suitability maps for plantain, with a distinction between the north-west part of the catchment with lower summer rainfall and more extreme summer temperatures. Even though both rainfall and temperature requirements are likely to be satisfied in the future, high waterlogging susceptibility throughout the catchment limits plantain's suitability to 70-80% over the majority of Glenelg Hopkins region (demonstrated in Figure 15). Median suitability is projected to increase from 77.0% in 1960-1990 to 78.4% by 2070, with the highest change in the north-west part of the catchment.

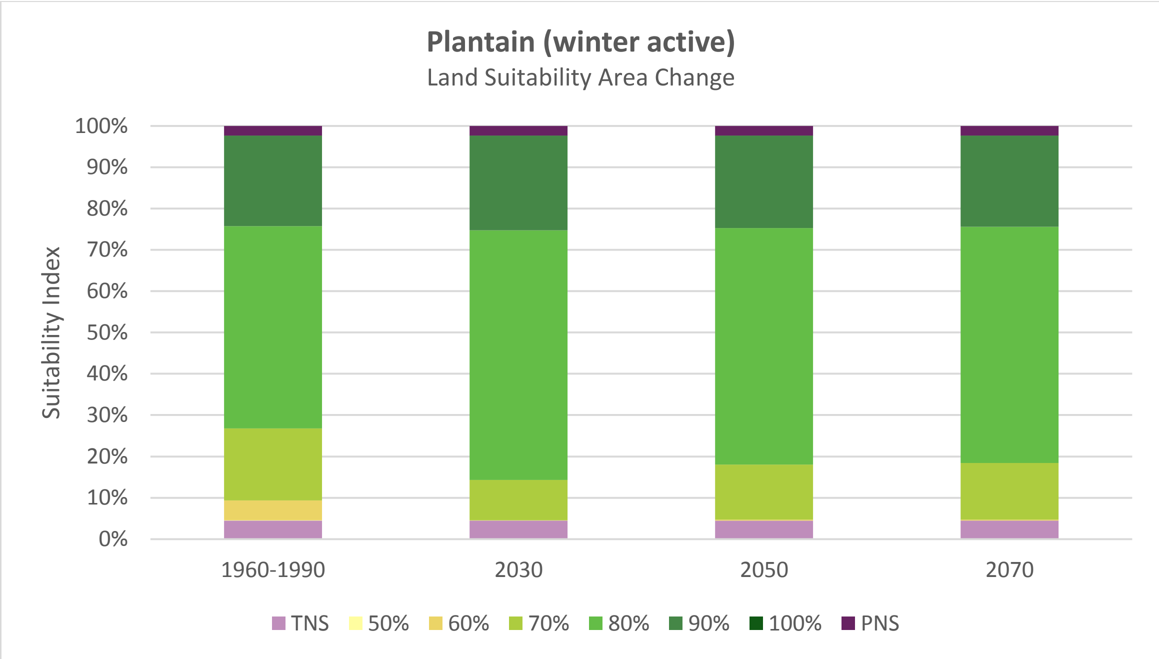

Figure 15 – Land suitability area change of winter active plantain

C. Legumes

Lucerne (summer active)

Scientific name: *Medicago sativa*
Common name: alfalfa
Baseline varieties: semi winter dormancy (3-5)

Lucerne is a temperate perennial legume with high nutritional value, high yield and good persistence under dry conditions, given appropriate grazing management is in place (PGG Wrightson Seeds 2016b; Mcdonald et al. 2003; The State of Victoria Department of Environment and Primary Industries 2012). Its drought tolerance is due to a taproot that can reach water from deep soil layers, high water use efficiency and responsiveness to summer rainfall or irrigation (PGG Wrightson Seeds 2016b; The State of Victoria Department of Environment and Primary Industries 2012). Model used in this project focused on semi-winter dormant lucerne varieties with peak production in spring, summer and early autumn (dormancy groups with their definitions can be found in Table 2). Lucerne has the potential to provide high quality feed during times of the year when most currently utilised pastures are dormant, but it has very low tolerance of continuous grazing (PGG Wrightson Seeds 2016b; Knox et al. 2006).

Table 2 – Dormancy groups of lucerne (source: adjusted from PGG Wrightson Seeds 2016)

DORMANCY	CHARACTER	DETAILS
1 – 3	Winter dormant	No winter growth – very short growing season
4 – 5	Semi-winter dormant	Very little winter growth, good persistence and summer quality for hay and or grazing
6 – 7	Winter active	Dense and reasonably persistent. Dual purpose types
8 – 9	Highly winter active	Good seedling vigour and fast recovery from cutting. Good short term stands for South West Victoria
10 - 11	Very highly winter active	Best suited to NSW and QLD for short term hey stands

Lucerne has low waterlogging, acidity and salinity tolerance (Knox et al. 2006). It also needs soils that are deep enough and easy to penetrate and develop its root system (The State of Victoria Department of Environment and Primary Industries 2012). It therefore performs best on lighter, free-draining soils where pH_{Ca} is > 5.0 due to its intolerance to high aluminium levels. Lucerne requires as little as 250 mm, but up to 700 mm of average annual rainfall (EverGraze 2008; Mcdonald et al. 2003; Smith 2012a). In areas with rainfall below 500 mm/yr, lucerne should be sown in autumn, and in late winter to early spring in areas with rainfall above 500 mm/yr (Morant A & Sargeant K 2013). Lucerne can be grown in temperatures between 10°C and 30°C, with ideal production temperature of 25°C (Department of Agriculture and Food 2017). Validation feedback repeatedly pointed out aluminium toxicity and insufficient subsoil drainage issues, hindering lucerne growth. It also pointed out the preference of light textured soils and hill tops, preventing waterlogging.

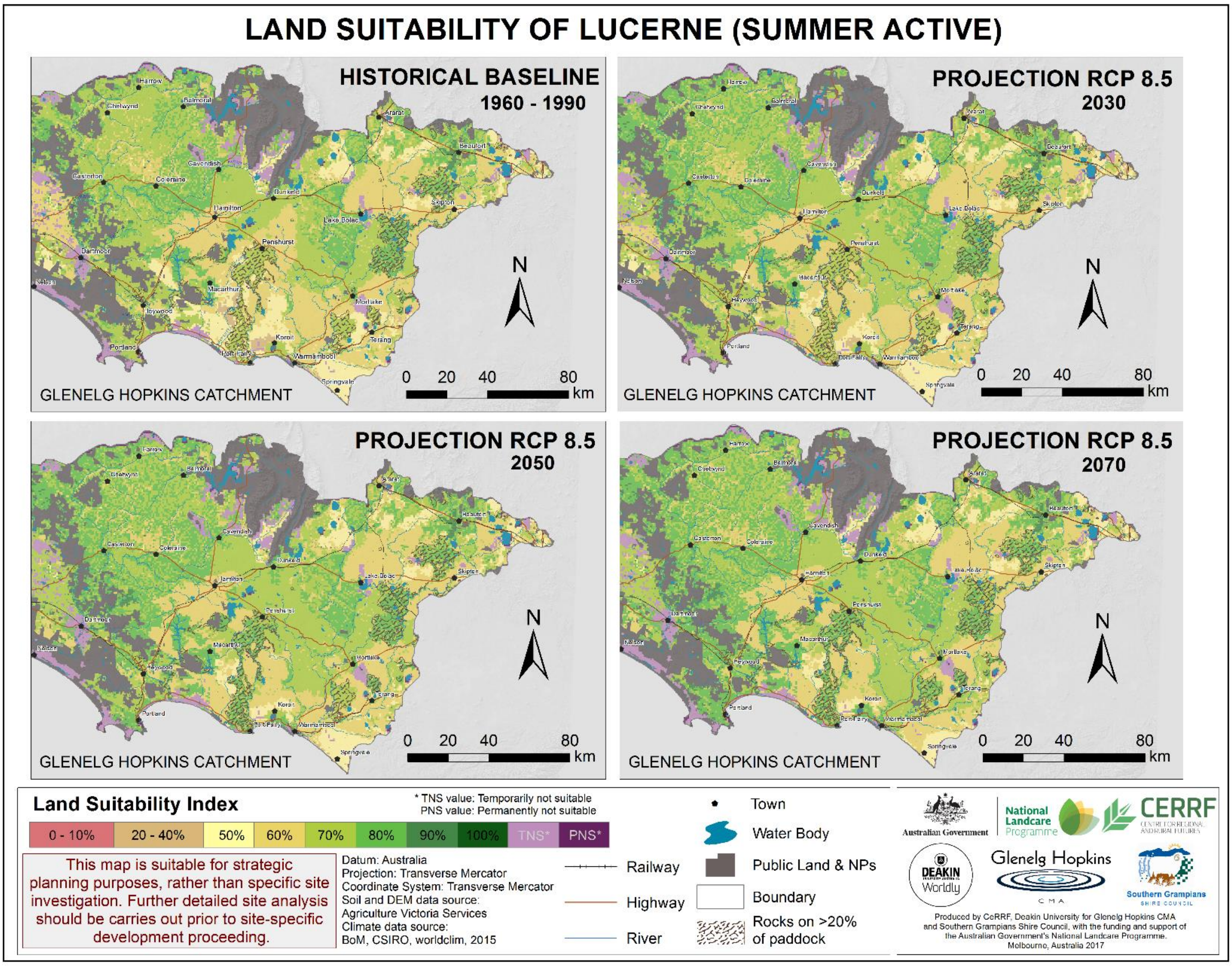

Figure 16 shows modelled suitability maps for lucerne with areas of pH_{Ca} < 4.6 in subsoil categorised as temporarily not suitable. Based on validation, soil factors were assigned higher importance than climate factors in the LSA model. Projected decrease in winter rainfall and increase in summer rainfall are likely to result in higher suitability, but due to the higher weight of soil conditions, any shifts in climate are not likely to have a significant impact on the overall lucerne's suitability in the region. As shown in Figure 17, median baseline suitability of lucerne is 63.3% and improves to 66.1% by 2070.

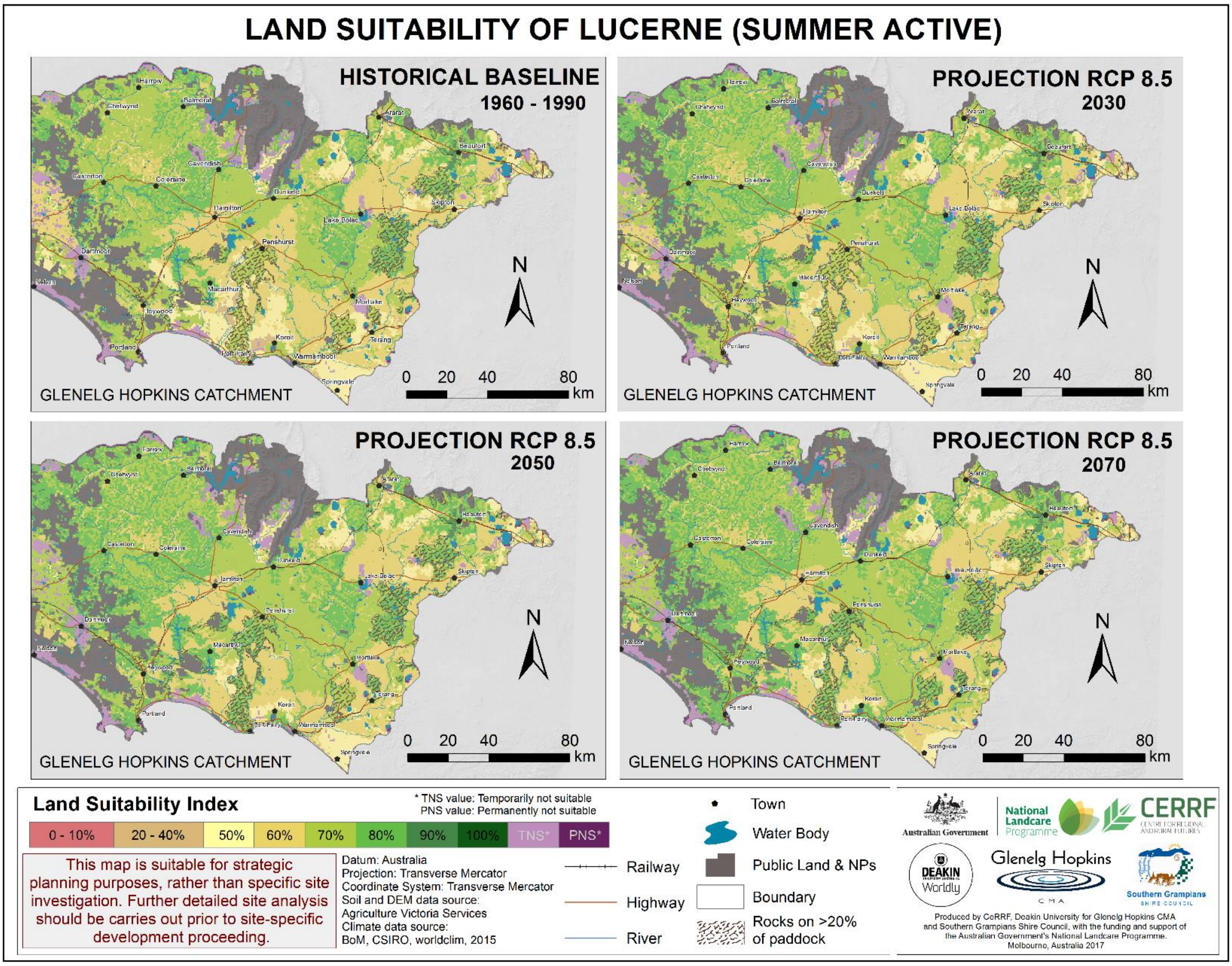

Figure 16 – Land suitability maps of summer active lucerne in Glenelg Hopkins region

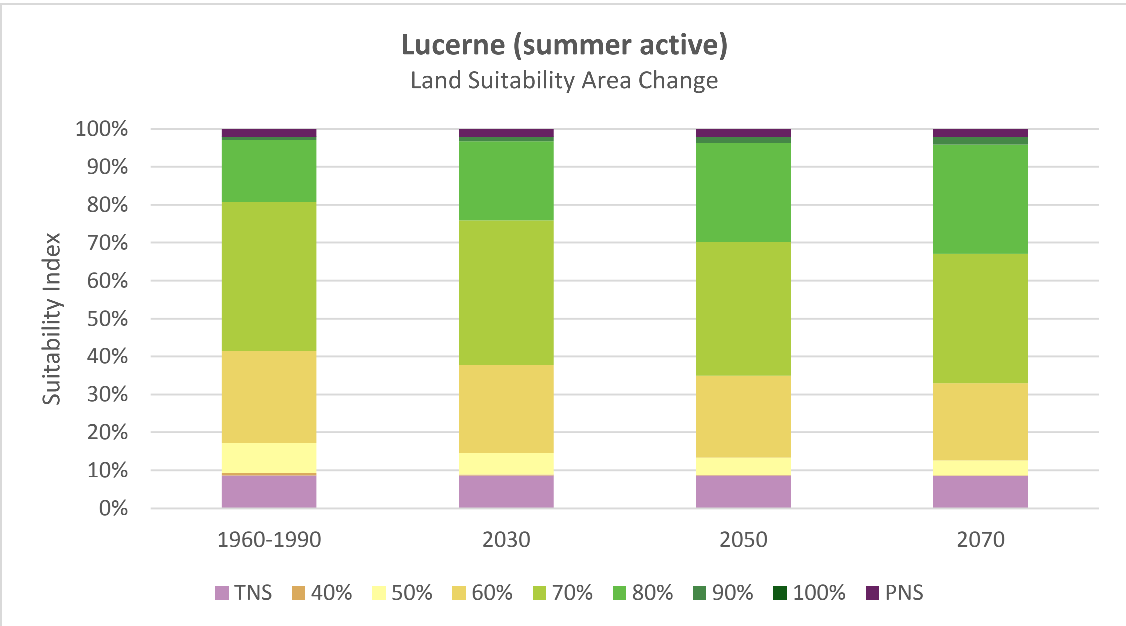

Figure 17 – Land suitability change of summer active lucerne

13. Concluding remarks

This report has been structured in several components, with a focus on the likely impacts of climate change on the pasture growth of perennial ryegrass, phalaris, panic grass, lucerne and plantain in the Glenelg Hopkins catchment. Figure 18 shows the overall trends in land suitability, indicating that phalaris, plantain, panic grass and lucerne are likely to become more suitable, whereas the suitability of perennial ryegrass is projected to decline. The overall median suitability index for pastures in Glenelg Hopkins region is 72.9% for baseline 1960-1990 likely to decrease to approx. 66.5% by 2070 (an average increase in suitability for pastures excluding ryegrass is 2.9% by 2070, but the high decline in perennial ryegrass suitability drives the total average land capability in 2070 down).

In general, decline in winter rainfall is likely to decrease land suitability for pasture species such as perennial ryegrass, reliant on higher moisture availability. Suitability of pasture species requiring less annual rainfall such as phalaris, or winter-dormant species responsive to summer rainfall, is projected to increase. The introduction of heat and drought resistant or summer active species to complement existing pasture systems in Glenelg Hopkins region, by supplying feed in months when stock has traditionally relied on silage, is significant. The likely increase in summer rainfall has a potential to stimulate such changes, but the projected unreliability of spring rainfall incidence can offset the benefits of higher moisture availability in summer by decreasing seedling vigour, hindering establishment, competitiveness and reducing persistence.

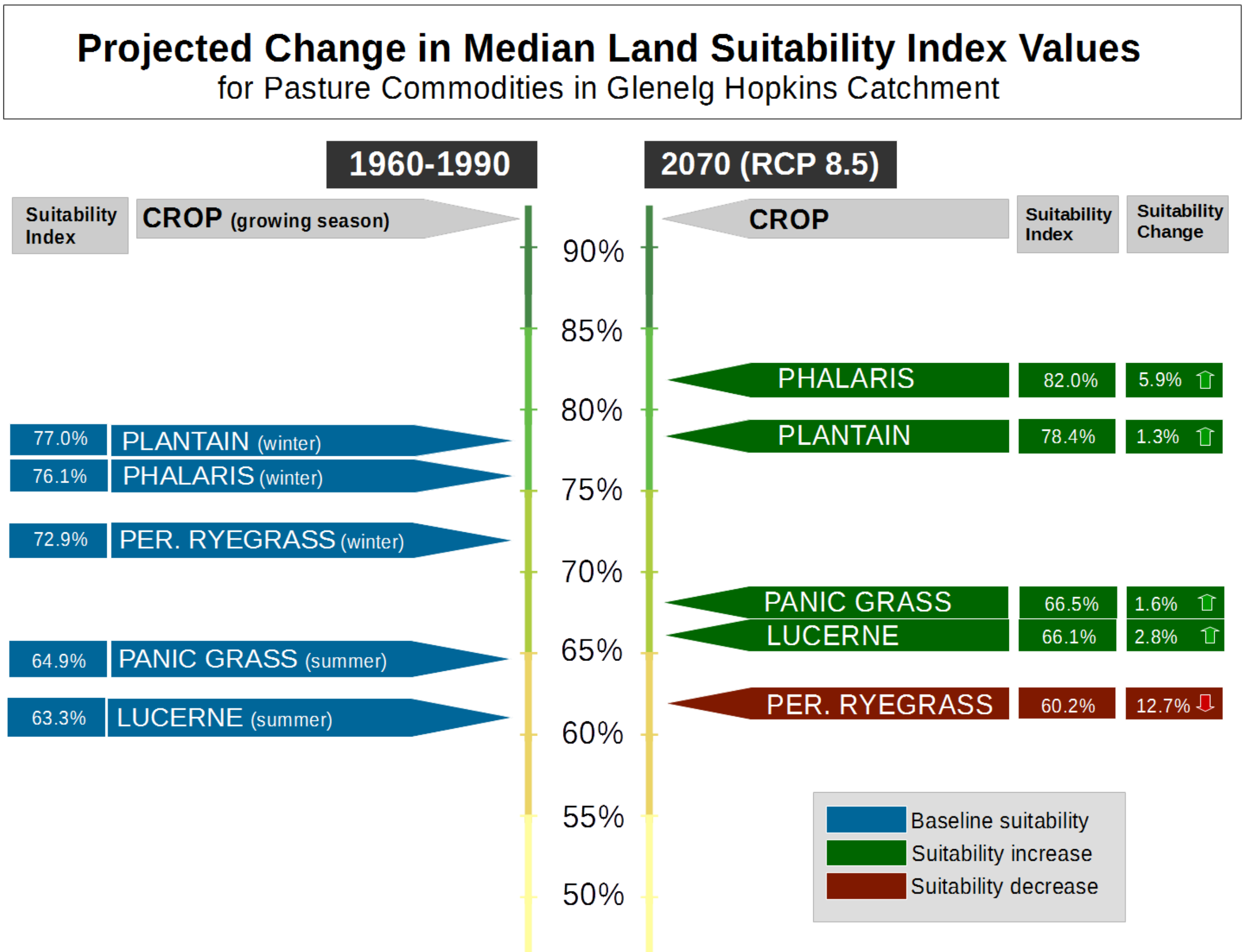

Figure 18 – Projected change in median land suitability index values for pastures

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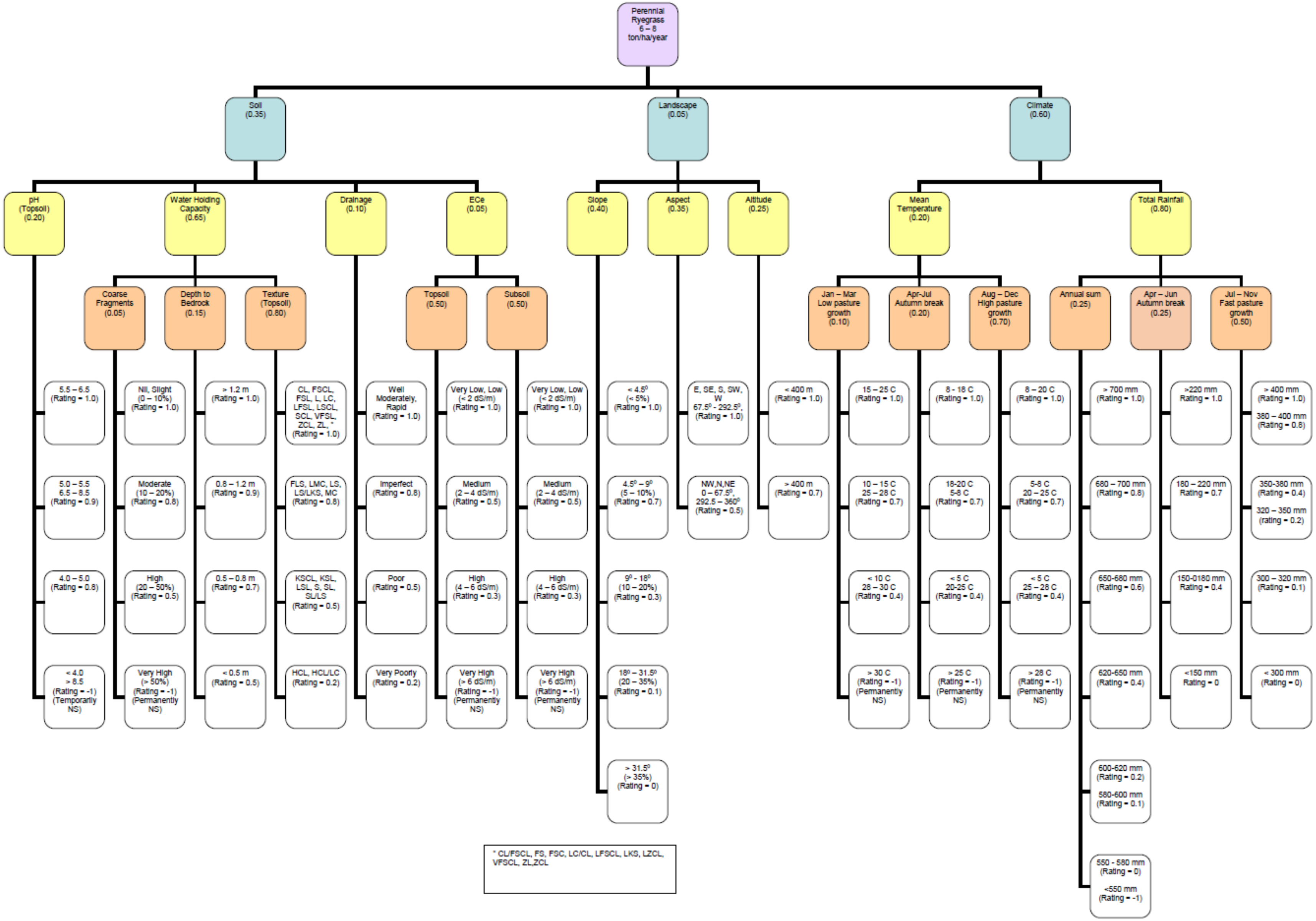
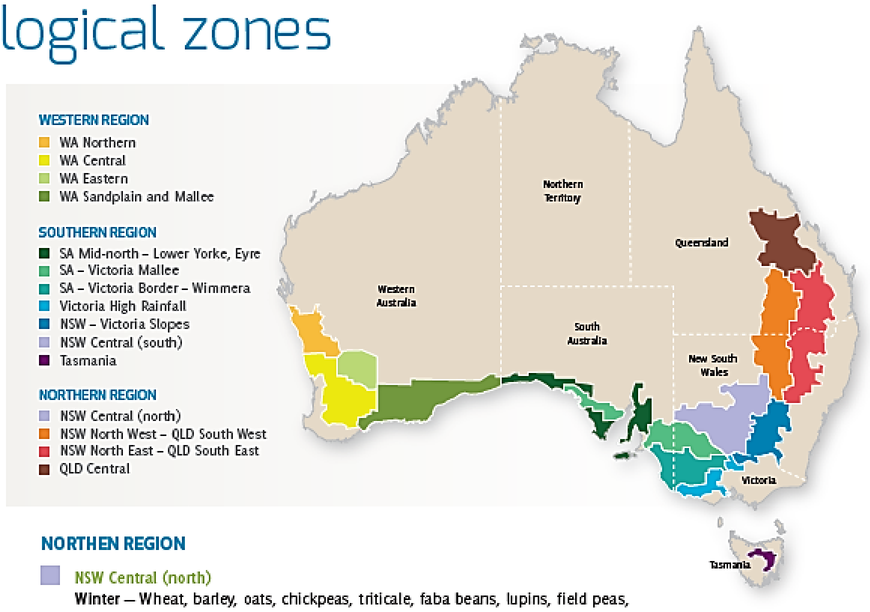
Appendix I – Perennial Ryegrass (winter active) hierarchy



Appendix II – Australian Agroecological Zones

Australian agroecological zones



WESTERN REGION

WA Northern

Winter – Wheat, barley, oats, triticale, lupins, field peas, canola, faba beans, chickpeas

WA Central

Winter – Wheat, barley, oats, triticale, cereal rye, lupins, field peas, canola, faba beans, chickpeas

WA Eastern

Winter – Wheat, barley, oats, triticale, lupins, field peas, canola, faba beans, chickpeas

WA Sandplain and Mallee

Winter – Wheat, barley, oats, triticale, lupins, field peas, canola, faba beans, chickpeas

SOUTHERN REGION

SA Mid-north – Lower Yorke, Eyre

Winter – Wheat, barley, oats, triticale, lupins, field peas, canola, chickpeas, faba beans, vetch, safflower

SA – Victoria Mallee

Winter – Wheat, barley, oats, triticale, cereal rye, lupins, vetch, canola, field peas, chickpeas, faba beans, safflower

SA – Victoria Border – Wimmera

Winter – Wheat, barley, oats, triticale, lupins, field peas, canola, chickpeas, faba beans, vetch, lentils, safflower

Victoria High Rainfall

Winter – Wheat, barley, oats, triticale, lupins, field peas, canola

NSW – Victoria Slopes

Winter – Wheat, barley, oats, triticale, lupins, field peas, canola

NSW Central (south)

Winter – Wheat, barley, oats, chickpeas, triticale, faba beans, lupins, field peas, canola, safflower

Tasmania

Winter – Wheat, barley, oats, triticale, lupins, field peas, canola

NORTHEN REGION

NSW Central (north)

Winter – Wheat, barley, oats, chickpeas, triticale, faba beans, lupins, field peas, canola, safflower

Summer – Sorghum, sunflowers, maize, mungbeans, soybeans, cotton

NSW North West – Qld South West

Winter – Wheat, barley, oats, chickpeas, triticale, faba beans

Summer – Sorghum, sunflowers, maize, mungbeans, soybeans, cotton

NSW North East – Qld South East

Winter – Wheat, barley, oats, chickpeas, triticale, faba beans, millet/panicum, safflower, linseed

Summer – Sorghum, sunflowers, maize, mungbeans, soybeans, peanuts, cotton

Qld Central

Winter – Wheat, barley, oats, chickpeas

Summer – Sorghum, sunflowers, maize, mungbeans, soybeans, cotton