LAND CAPABILITY ASSESSMENT

Of Glenelg Hopkins Catchment

Technical Report: **Broadacre cropping**

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"This project is supported by the Glenelg Hopkins CMA with funding from the Australia Government's National Landcare Programme."

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 National Landcare Programme, Southern Grampians Shire Council and Deakin University. This report outlines an analysis of the potential implications of regional climate change on cropping, through GIS modelling of broadacre crops barley (autumn sown), red wheat (autumn sown), quinoa (spring and autumn sown), chickpeas (autumn sown), faba beans (autumn sown), mustard seed (autumn sown), sunflower seed (spring sown) and industrial hemp (spring and autumn sown). 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 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 hotter and drier, particularly in the north-east part of the catchment, the traditional cropping zone. The implications on cropping in the region may be significant. Projected changes to the values of key climatic variables, such as rainfall and temperature, could potentially impact the optimal growth conditions for these commodities. Increased temperatures could have negative impacts in terms of increased heat stress, increased evapotranspiration (and therefore increased irrigation requirements) and changes to phenology that impact on sowing and harvest times.

The modelling indicates a likely shift of the traditional cropping zone from the northeast corner of the catchment further south and west, following the projected rainfall decline. Such a shift may increase suitability in the south, specifically for winter cropping commodities sensitive to waterlogging, but the equivalent decrease of precipitation is likely to cause water shortages and subsequent suitability decline in the traditional cropping zone around Ararat, Tatyoon, Lake Bolac and Streatham. Southward spread of cropping can already be observed, but other high-value land uses (such as dairy or cattle and sheep grazing along the coast) are likely to continue offering larger returns. This report looks at alternative commodities that are summer grown, 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.

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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
IR	Irrigation Requirement
LSA	Land Suitability Assessment
MCA	Multi Criteria Analysis
NASA	National Aeronautics and Space Administration
PNS	Permanently Not Suitable
RCP	Representative Concentration Pathways
Re	Effective Rainfall
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 yield of selected cropping commodities. A list of 8 broadacre crops 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 crop rotation. 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 cropping patterns 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 crops can be viably produced 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.

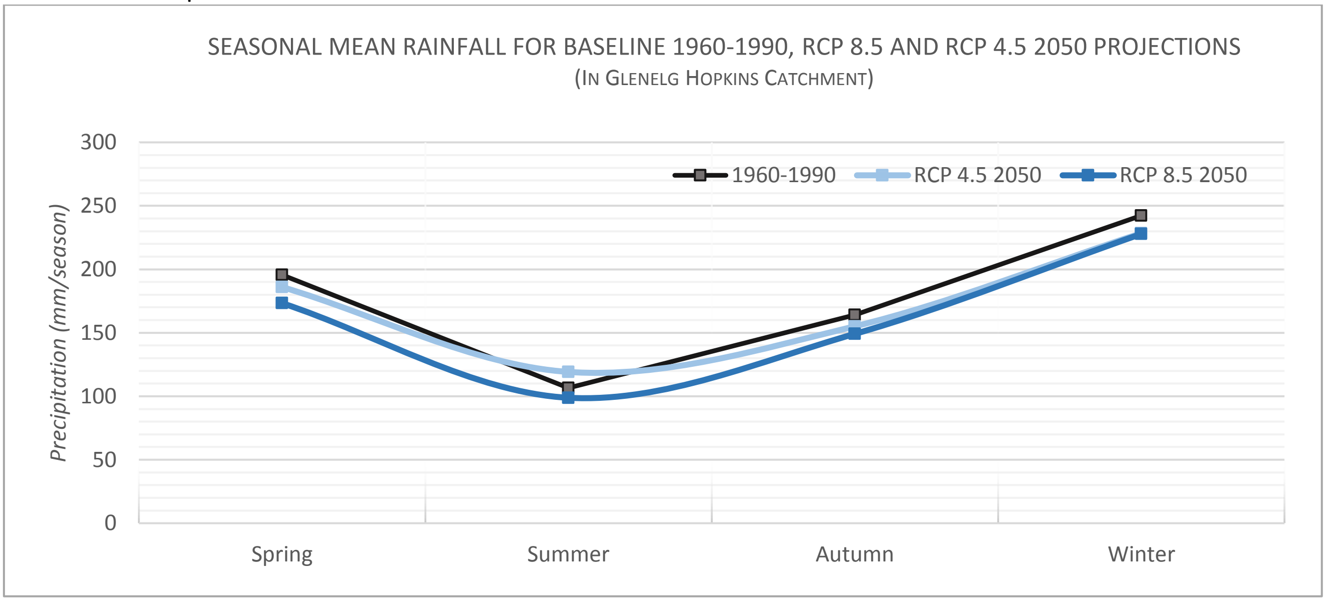

Figure 1 - Seasonal Mean Rainfall for baseline, RCP 4.5 and RCP 8.5 2050

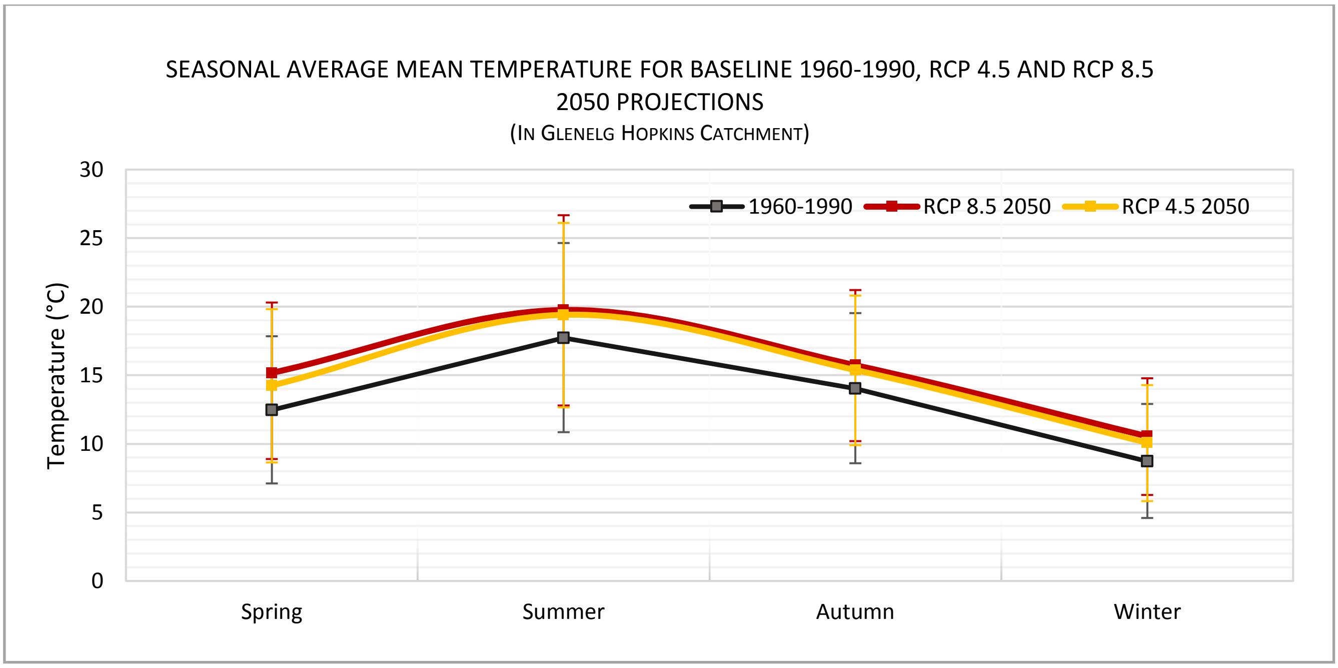

Figure 2 - Seasonal average of mean temperature for baseline, RCP 4.5 and RCP 8.5 2050 (with deviation bars showing average maximum and minimum temperatures for particular season)

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 crops 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.

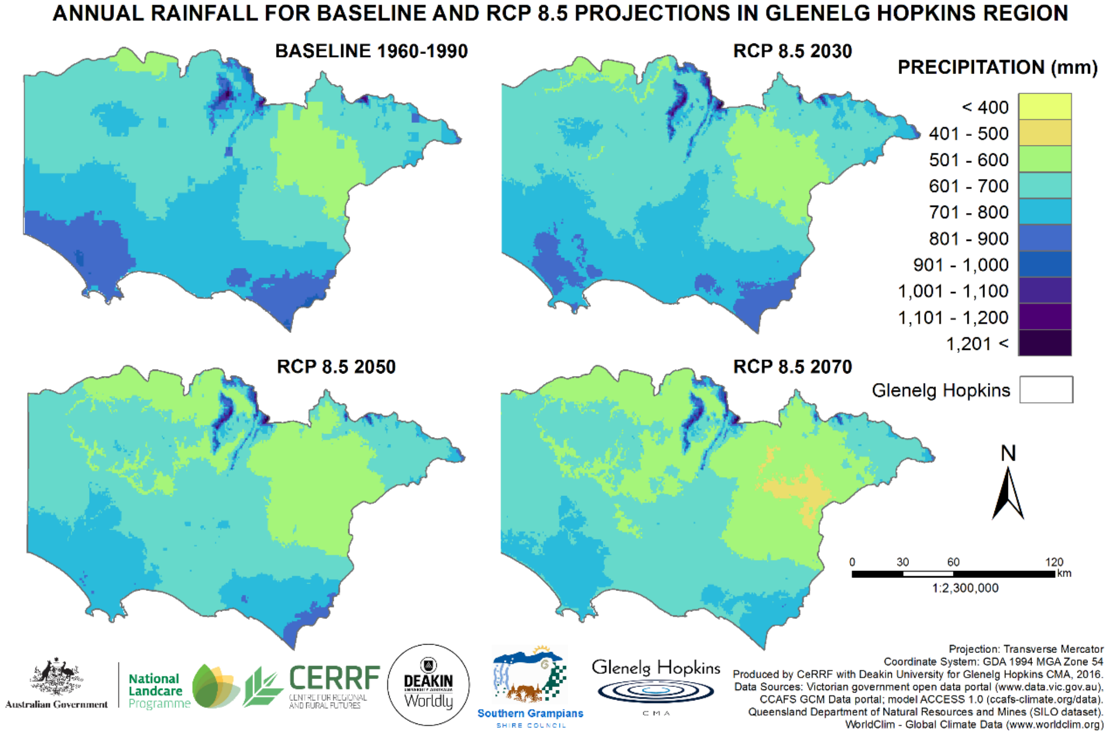

Figure 3 - Mean annual rainfall for baseline 1960-1990 and RCP 8.5 projections

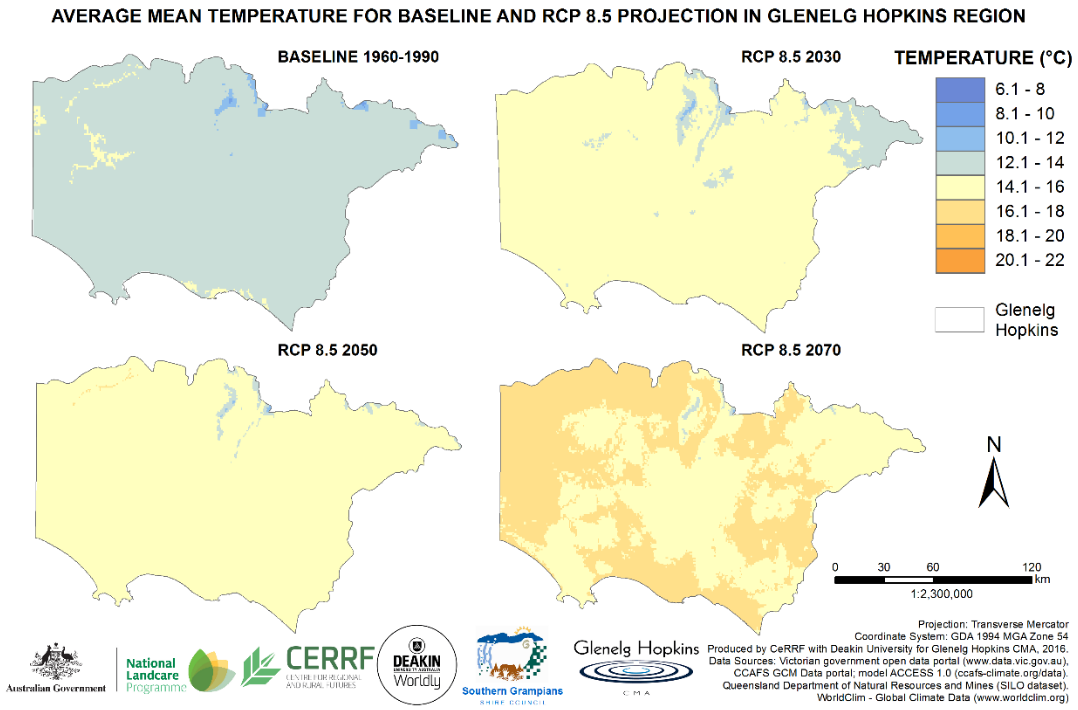

Figure 4 - Annual Mean Temperature for baseline 1960-1990 and RCP 8.5 projections

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 crop plants.

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.

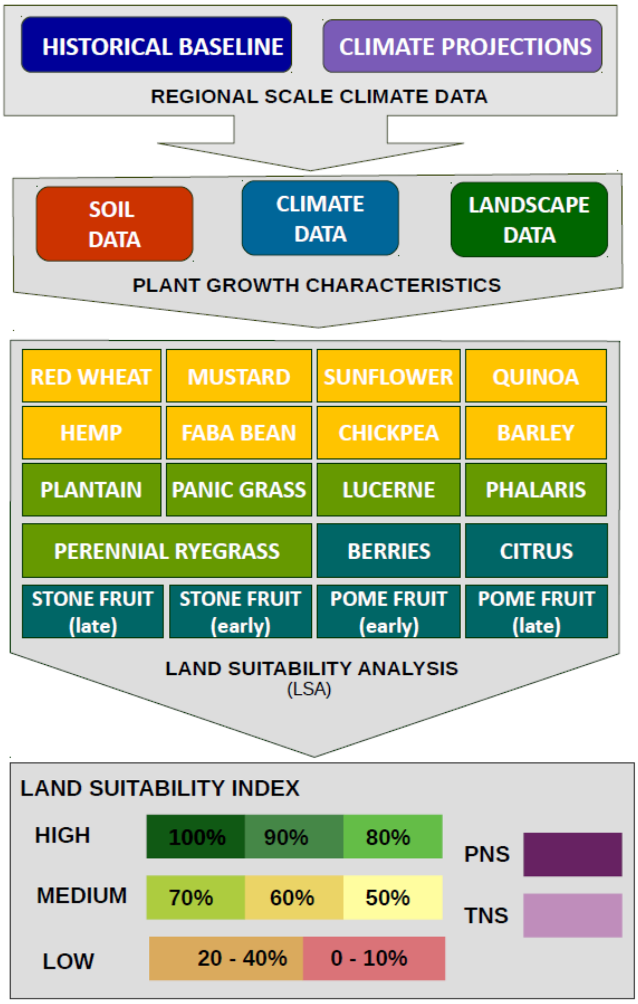

Figure 5 – LSA methodology

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 cropping 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 crop production; for instance, the effect that changing climatic conditions may have on bees and pollination, or on crop disease status. It also does not consider management practices that also significantly influence crop yields. 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.

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 crops, 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 yields 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 crops. 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 Glenelg Highway, being traditionally thought of as a divide between cropping and pasture based land-use, has often been referenced as a suitability demarcation. The overall validation feedback and a number of successful cropping farms established further south suggest a likely shift of the notional cropping line closer to the Hamilton Hwy. The climate conditions in north-west are favourable for cropping, as seen on the suitability maps, but areas of sandy soils and landscape restrictions complicating cultivation and use of machinery due to its hilliness, decrease its broadacre cropping potential. This 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 growing season, amending the spring and autumn break windows suggestive of planting and harvest timing. These models have been therefore amended based on the limited feedback and any available trials in close vicinity to the catchment or other parts of Australia with similar biophysical conditions. All the assumptions made are detailed at the pertinent commodity-specific sections of this report.

Due to high waterlogging susceptibility of the regions soils, mentioned at every validation session, a rainfall cut-off has been introduced into the models to control for suitability in areas with good drainage, but excessive rainfall. For most winter crops, that cut-off has been set between 550 and 650 mm of rainfall per growing season (depending on the crop requirements and sensitivity) after which the suitability ranking rapidly drops off. A waterlogging susceptibility data supplied by the CMA has also been imbedded within this project's models. 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 Al toxicity issue.

12. Crop Production

As mentioned in Chapter 8 on Climate change and Agriculture, Glenelg Hopkins catchment has very diverse biophysical conditions, extending over two major climatic zones. Those are represented in the agroecological zones defined by the Australian Export Grains Innovation Centre (Appendix II) as:

- **South Australia – Victoria Border – Wimmera**

Winter dominant rainfall with major crops such as wheat, barley, oats, triticale, lupins, field peas, canola, chickpeas, faba beans, vetch, lentils, safflower

- **Victoria High Rainfall**

Winter dominant rainfall with major crops such as wheat, barley, oats, triticale, lupins, field peas, canola

Majority of the catchment has been traditionally dominated by pastures, particularly the coastal areas and the hilly north-west. The feedback received during validation suggests a recent trend of cropping to extend further south. Consistent with those observations, the projected changes in climate are very likely to cause a shift of agroecological zones southward. Likely increase in summer rainfall would suggest a potential for the region to introduce more summer crops into the cropping mix. Although, based on the validation feedback from regional croppers, it is predominantly the spring rainfall that determines the crop's success. With hot and dry springs becoming more prevalent, the soil moisture content is insufficient and is likely to result in yield potential decline. As demonstrated in Figure 6, an occasional wet year, such as 2016 is likely to significantly increase production regardless of commodity prices shown in Figure 7, that otherwise influence production decisions.

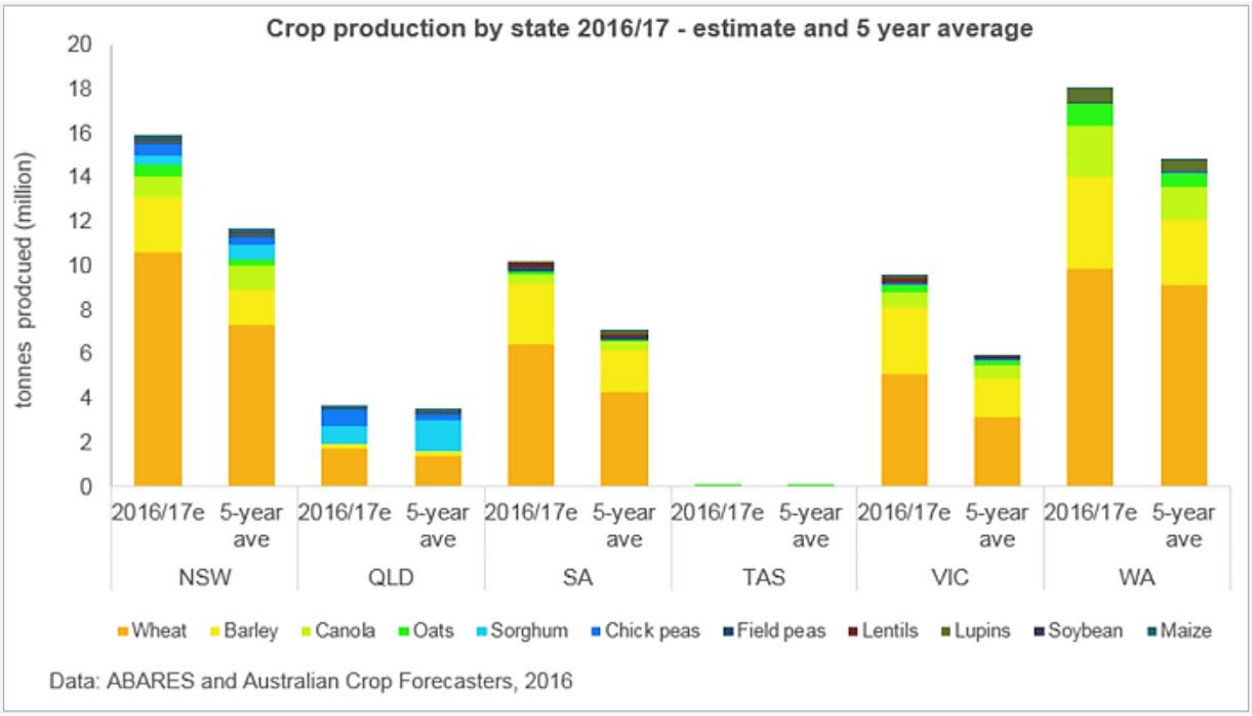

Figure 6 – Crop production by state for 2016/2017 and 5 year average (Source: Australian Crop Update April 2017)(AgAnswers 2017)

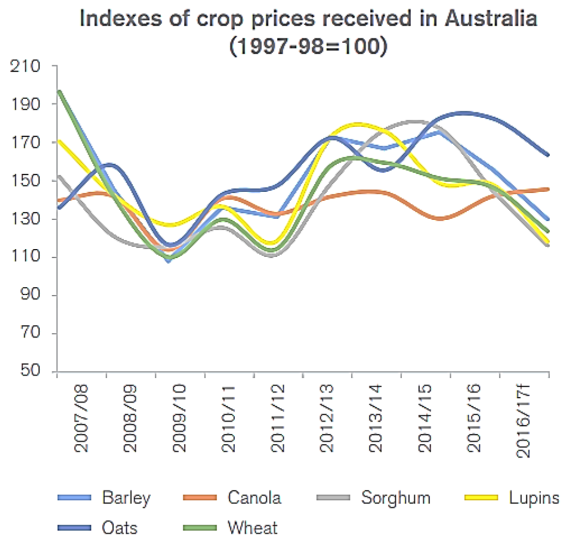

Figure 7 – Indexes of crop prices in Australia for 2007 - 2017

The production of crop commodities in the Southern and Western Victoria have been relatively stable during the past 5 years, as shown in Figure 8. Similarly to the rest of Victoria, majority of the produce are grains, namely barley and wheat, followed by canola and other oilseeds, and a low share of pulses/legumes. As presented in Figure 9, the overall area of cropping within the Glenelg Hopkins Catchment has been increasing from 15% in 2011/2012 to 22% in 2014/2015 (ABS 2016). Accounts from local farmers and agricultural groups during suitability model validation suggest a shift of cropping production south.

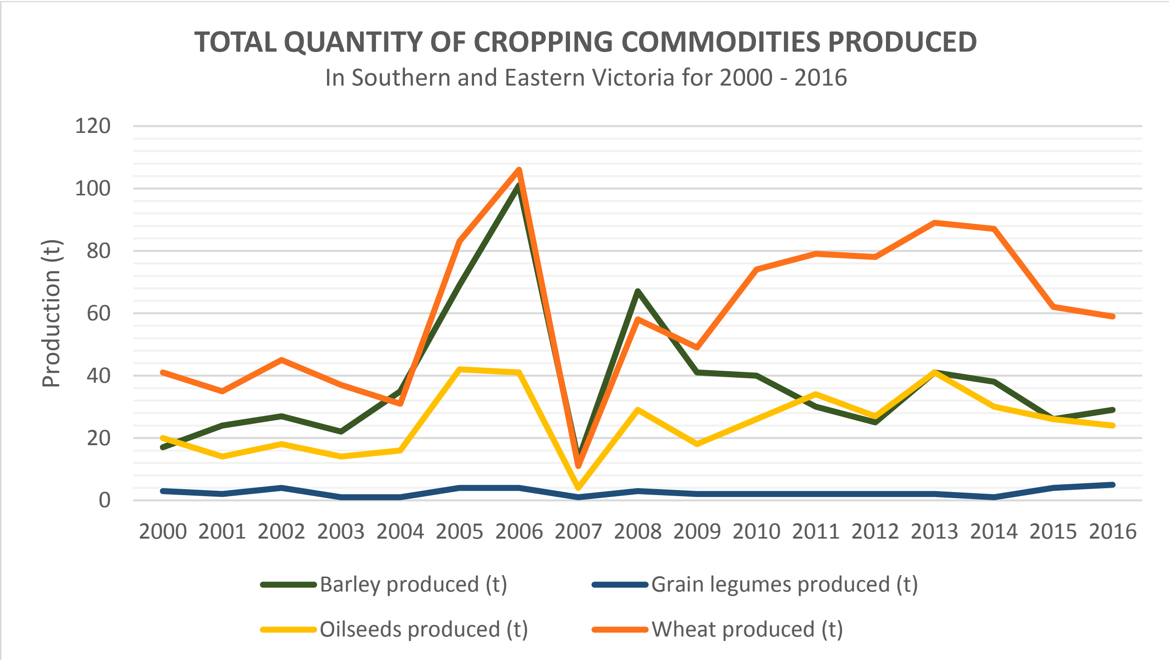

Figure 8 – Total Quantity of Cropping Commodities Produced in Southern and Eastern Victoria for 2000-2016 in tonnes (Source: ABARES, 2016) (ABARES 2017)

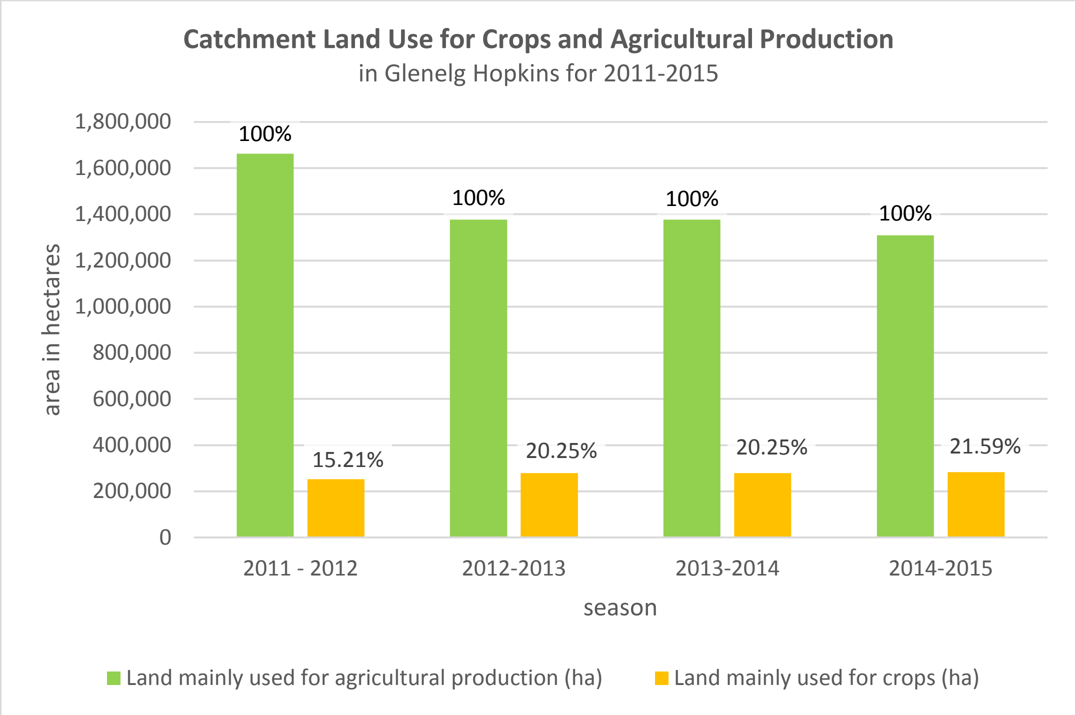

Figure 9 – Broadacre Cropping by Percentage of the Total Estimated Area of Agricultural Land in Glenelg Hopkins Catchment Area for 2011 - 2015 (Source: ABS, 2016)

A. Grains

Barley (autumn sown)

Scientific name: *Hordeum vulgare*
Common name: Winter Barley, Gars
Family: Gramineae

Production of barley in Australia is the second largest after wheat (same as in Southwest Victoria, demonstrated in Figure 8), with almost 70% being exported (Neil et al. 2010). As shown in Figure 10, the extent of barley growing area across Victoria has been rather stable over the past 10 years, with a recent improvements in productivity increasing the overall production volume (ABARES 2017). Similarly to other grain crops, the 2016/2017 season has been exceptional in terms of production (see Figure 6), but short term forecasts predict a decline of barley production due to low commodity prices as demonstrated in Figure 7 (Rural Bank Ltd & Bendigo and Adeleide Bank Limited 2016; AgAnswers 2017).

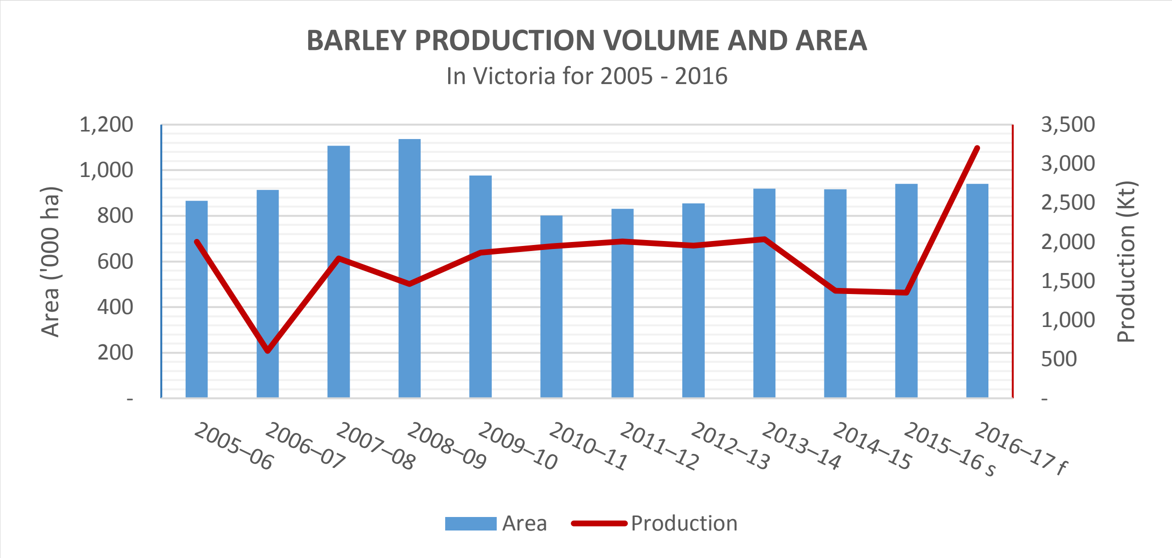

Figure 10 – Barley production in Victoria by volume and area for 2005 – 2016 (Source: ABARES, 2017)

Based on National Variety Trials done by the Grains Research & Development Corporation GRDC initiative around Streatham and Hamilton, barley has been modelled as a long, cold season grain crop sown in late autumn (mid-May) with target yield of 5 – 8 t/ha (GRDC: Grains Research & Development Corporation 2017c; Grains Research & Development Corporation 2016a). It is more frost tolerant at flowering than wheat and can be therefore planted earlier in the season (Grains Research & Development Corporation 2016a; Kelly et al. 2015). Profitability of barley is determined by grain quality (differentiating between barley for malt and for feed) and yield. The quality is partially influenced by weather conditions with early planting being more likely to produce higher yields, larger grain size and lower protein levels that all determine the malting quality. Late maturing in hot and dry weather reduces grain size and subsequently the quality and yield. (Grains Research & Development Corporation 2016a; Macquarie Franklin 2011)

Winter barley needs a vernalisation period of low temperatures between 0 and 10°C (Neil et al. 2010). The different length of vernalisation needed among varieties is not considered in this model. Paddock selection also has a crucial impact on production yield and quality. Slope should not exceed 25%, depending on the risk of soil erosion and machinery access, but also run-off accumulation at the low-lying areas. Barley can be grown on a range of soil textures, from heavy clays to light and sandy loams, as long as they are well drained (DPIWE Tasmania 2012a). It has a higher salinity tolerance than wheat but is more sensitive to soil acidity, affecting yields if pH ($CaCl_2$) is less than 4.5, and to waterlogging (Department of Agriculture Forestry and Fisheries 2009;

Grains Research & Development Corporation 2016a; Neil et al. 2010). Validation feedback received from farmers pointed out waterlogging as one of the most limiting factors. Rainfall cut-off has been hence introduced into the LSA model, radically decreasing suitability index of areas where seasonal rainfall reaches over 550 mm.

Figure 11 shows the land suitability maps for barley as modelled for the historical baseline of 1960 – 1990 and subsequent climate change projections RCP 8.5 out to 2070. The baseline map shows high suitability in the drier, traditional cropping areas of the catchment with rainfall between 300 – 500 mm per growing season. Any additional rainfall decreases suitability due to increased risk of waterlogging and associated diseases. Projected decrease in winter rainfall results in higher suitability further south, suggesting the potential of cropping to expand to what have traditionally been pasture-dominated areas.

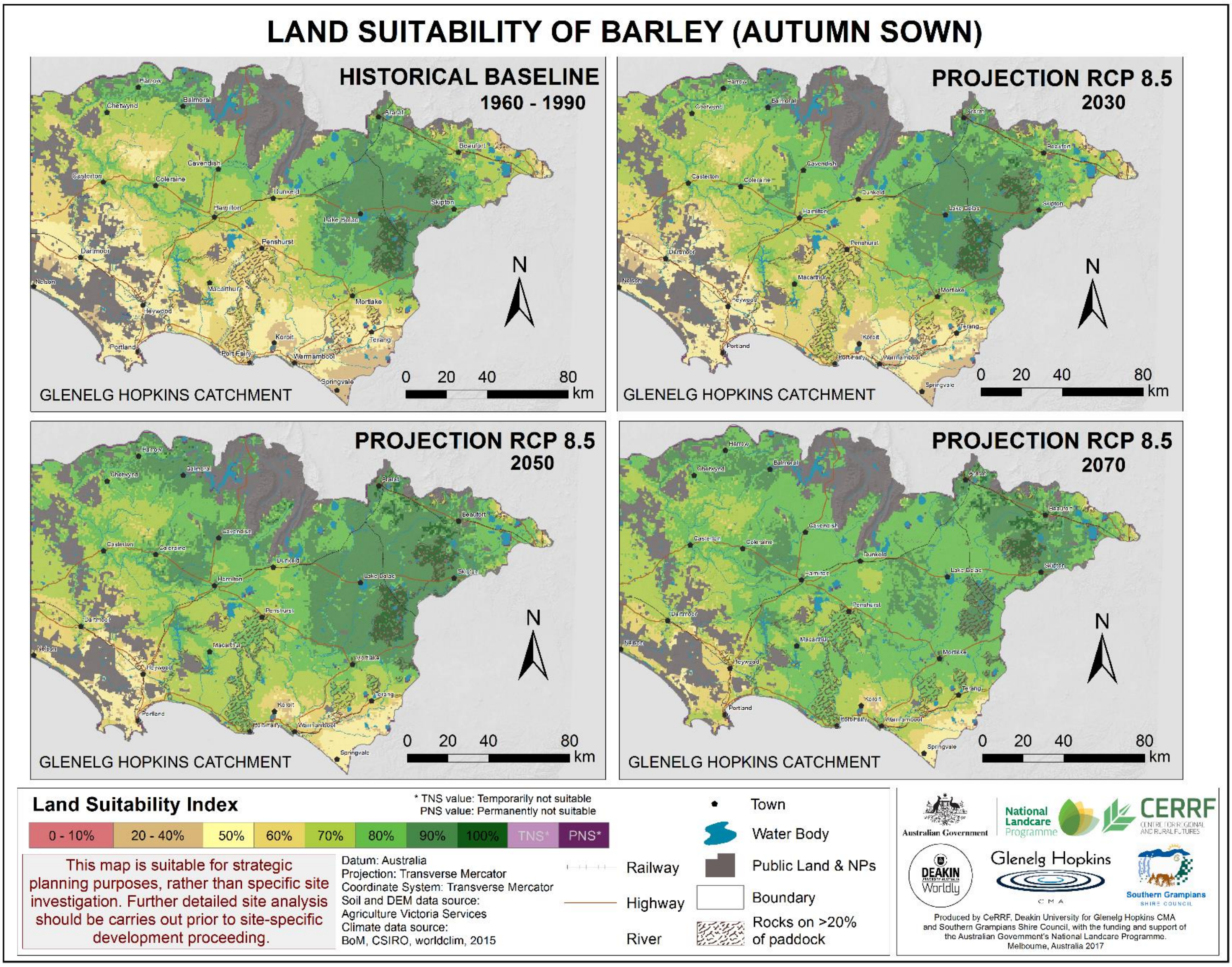

Figure 11 – Barley (autumn sown) land use suitability maps for baseline of 1960-1990 and climate projections RCP 8.5 for 2030, 2050 and 2070

Temperature shifts are likely to be less dramatic, not having a significant impact on suitability until 2070, when the increase in temperature in the northern part of the catchment is likely to decrease its suitability. Nevertheless, barley is projected to be highly suitable for approximately 2/3 of the catchment by 2070, as shown in Figure 12. Despite climate being the driving factor in barley's land suitability model, soil parameters such as pH, drainage and waterlogging susceptibility also have a significant weight on the overall suitability index. Stoniness, preventing access or successful operation of machinery has also been taken into account and is presented as an overlay of paddocks with rocks on more than 20% of their area in Figure 11.

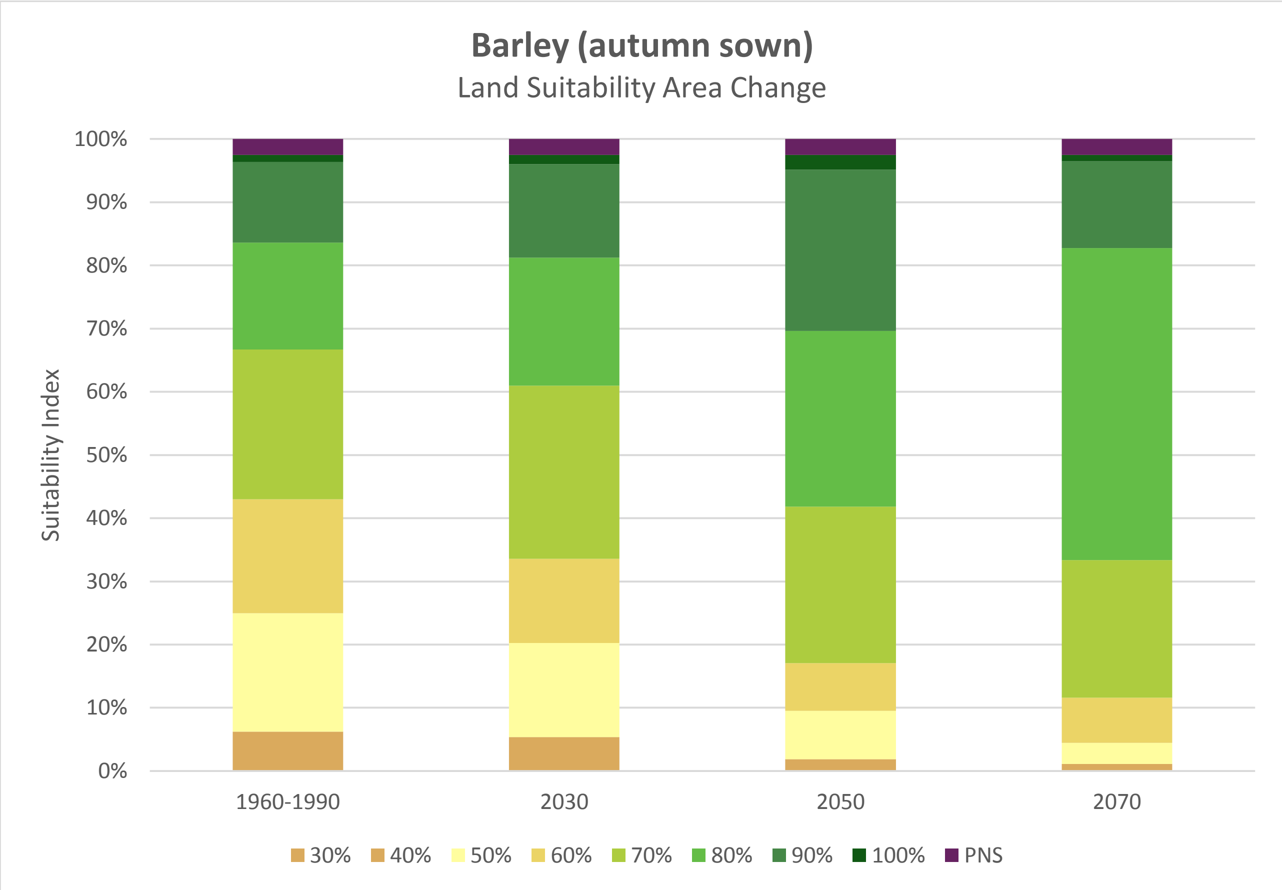

Figure 12 – Land Suitability Area Change for Autumn Sown Barley

Red Wheat (autumn sown)

Scientific name: *Triticum aestivum*
Common name: Red Wheat
Family: Poaceae

Wheat is a grain with the highest production in Australia (same as in Southwest Victoria, demonstrated in Figure 8), with almost 70% of production being exported (NSW DPI 2007). As shown in Figure 13, the extent of wheat production area across Victoria has been rather stable over the past 10 years, with a recent increase in productivity (ABARES 2017). Similarly to other grain crops, the 2016/2017 season has been exceptional in terms of production (see Figure 6), but short term forecasts predict a decline of wheat production due to low commodity prices as demonstrated in Figure 13 (Rural Bank Ltd & Bendigo and Adeleide Bank Limited 2016; AgAnswers 2017).

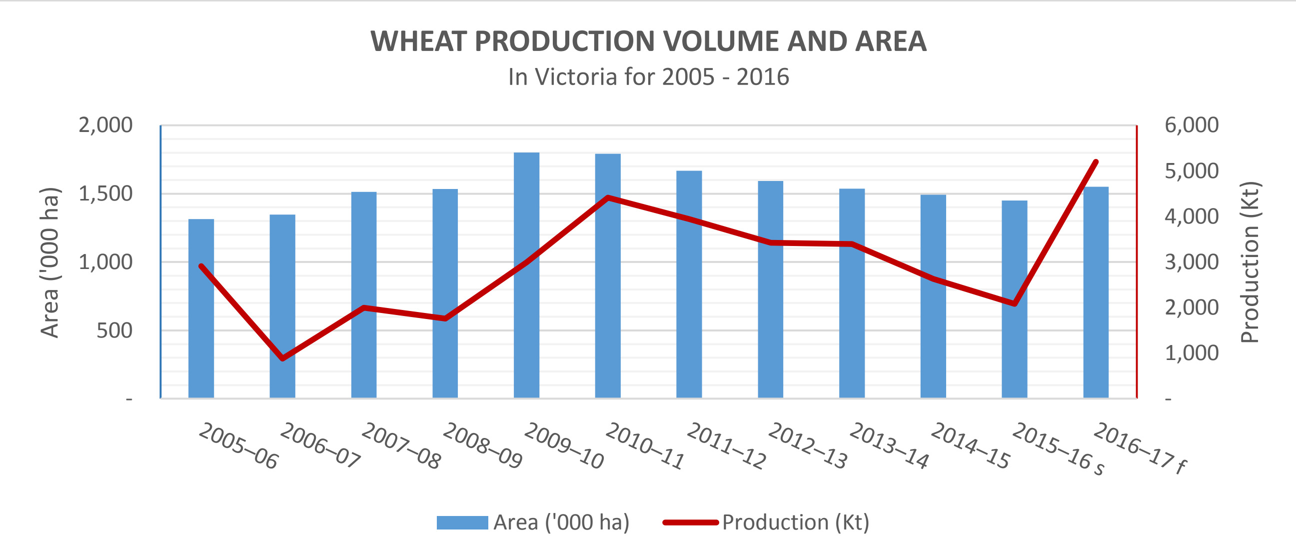

Figure 13 – Wheat production volume and area in Victoria for 2005 – 2016 (Source: ABARES)

Based on National Variety Trials done by the GRDC initiative around Streatham and Hamilton, red wheat has been modelled as a long, cold season grain crop sown in mid to late autumn with target yield of 5 – 8 t/ha (GRDC: Grains Research & Development Corporation 2017c; Grains Research & Development Corporation 2016a). High soil temperatures during sowing are likely to hinder establishment, the temperature range for germination in this model is 12 – 25°C (Grains Research & Development Corporation 2016b; E. Acevedo et al. 2015). Winter wheat needs a vernalisation period of low temperatures between 0 and 10°C (Neil et al. 2010). The different length of vernalisation needed among varieties is not considered in this model. Even though wheat needs a period of low temperatures, frost at flowering stage (end of spring) can cause the grain not to fill, resulting in reduced yield (E. Acevedo et al. 2015; Bill Cotching et al. 2012). Paddock selection also has a crucial impact on production yield and quality. Slope should not exceed 25%, depending on the risk of soil erosion and machinery access, but also run-off accumulation at the low-lying areas. Soil type and drainage are interrelated factors that strongly affect land suitability, although wheat is less sensitive to waterlogging than barley. Red wheat can be grown on a range of soil textures excluding sandy soils susceptible to erosion. It is suitable to well, moderately and excessively drained soils (DPIWE Tasmania 2012a). Soil acidity affects yields if pH (H_2O) is less than 5.0, with ideal range between 6.0 and 6.5 (Bill Cotching et al. 2012; E. Acevedo et al. 2015; NSW DPI 2007). It is less tolerant to soil salinity than barley. Areas with ECse < 3dS/m in topsoil are unsuitable(Bill Cotching et al. 2012).

Validation feedback received from farmers reported red wheat being higher yielding than white wheat. It also stressed the importance of good drainage and sufficient soil depth, but pointed out its tolerance to acidic subsoils. Due to potential waterlogging issues in the south of the catchment, rainfall cut-off has been introduced into the LSA model, radically decreasing suitability index of areas where seasonal rainfall reaches over 650 mm.

Figure 14 shows the land suitability maps for red wheat as modelled for the historical baseline of 1960 – 1990 and subsequent climate change projections RCP 8.5 out to 2070. The baseline map shows the highest suitability of 90 – 100% in the drier, traditional cropping areas of the catchment with rainfall between 300 – 550 mm per growing season. Any additional rainfall decreases suitability due to increased risk of waterlogging, but due to wheat's higher tolerance, 70% of the catchment area at baseline is highly suitable for red wheat. Projected decrease in winter rainfall results in increasing suitability further south, suggesting the potential of cropping to expand to what have traditionally been pasture-dominated areas.

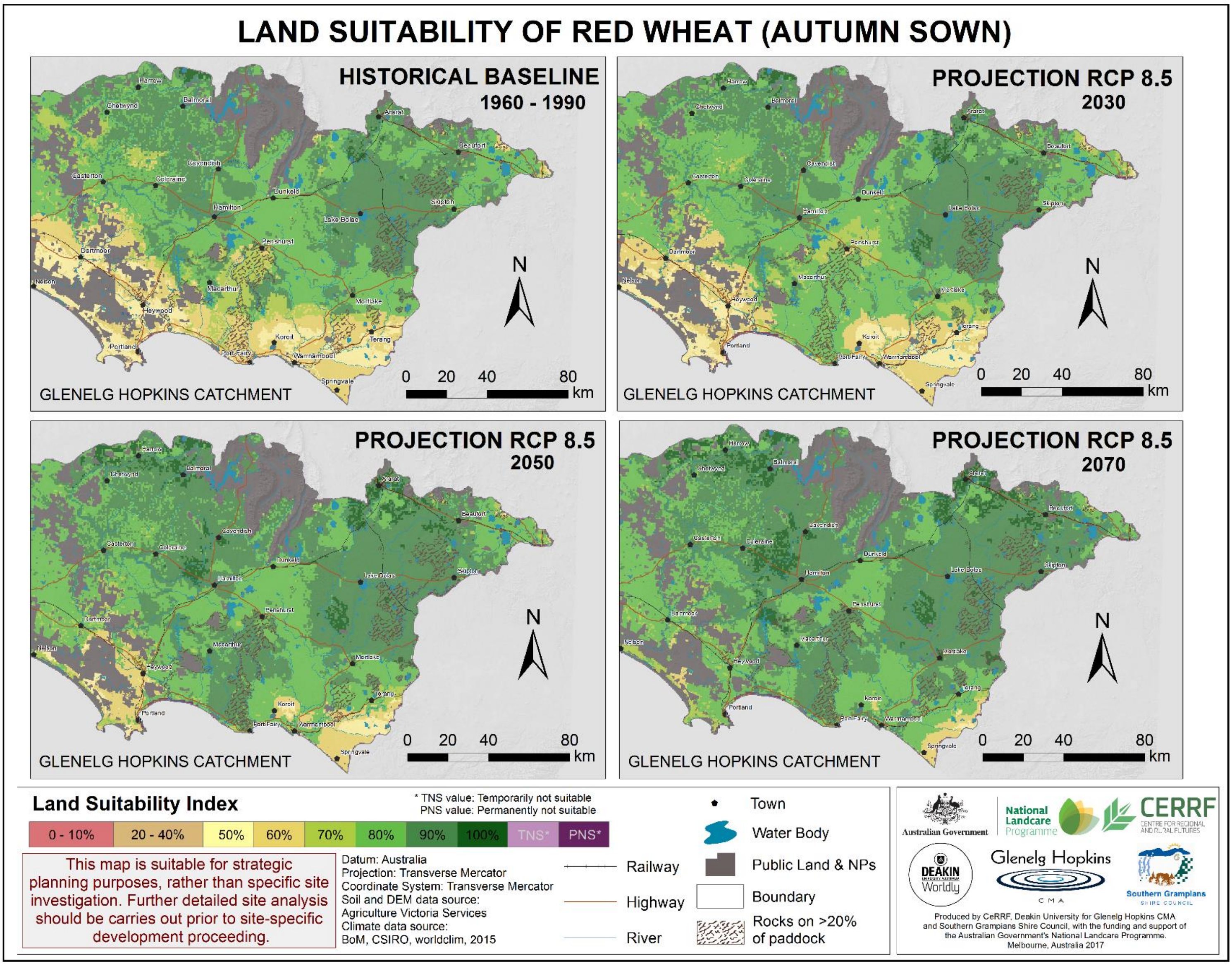

Figure 14 – Red Wheat (autumn sown) land use suitability maps for baseline of 1960-1990 and climate projections RCP 8.5 for 2030, 2050 and 2070

Temperature shifts are likely to be less dramatic, not having a significant impact on suitability. Red wheat is projected to be highly suitable for approximately 90% of the catchment by 2070, as shown in Figure 15. Despite climate being the driving factor in wheat's land suitability model, soil parameters such as salinity, drainage and waterlogging susceptibility also have a significant weight in the overall suitability index. Stoniness, preventing access or successful operation of machinery has also been taken into account and is presented as an overlay of paddocks with rocks on more than 20% of their area in Figure 14.

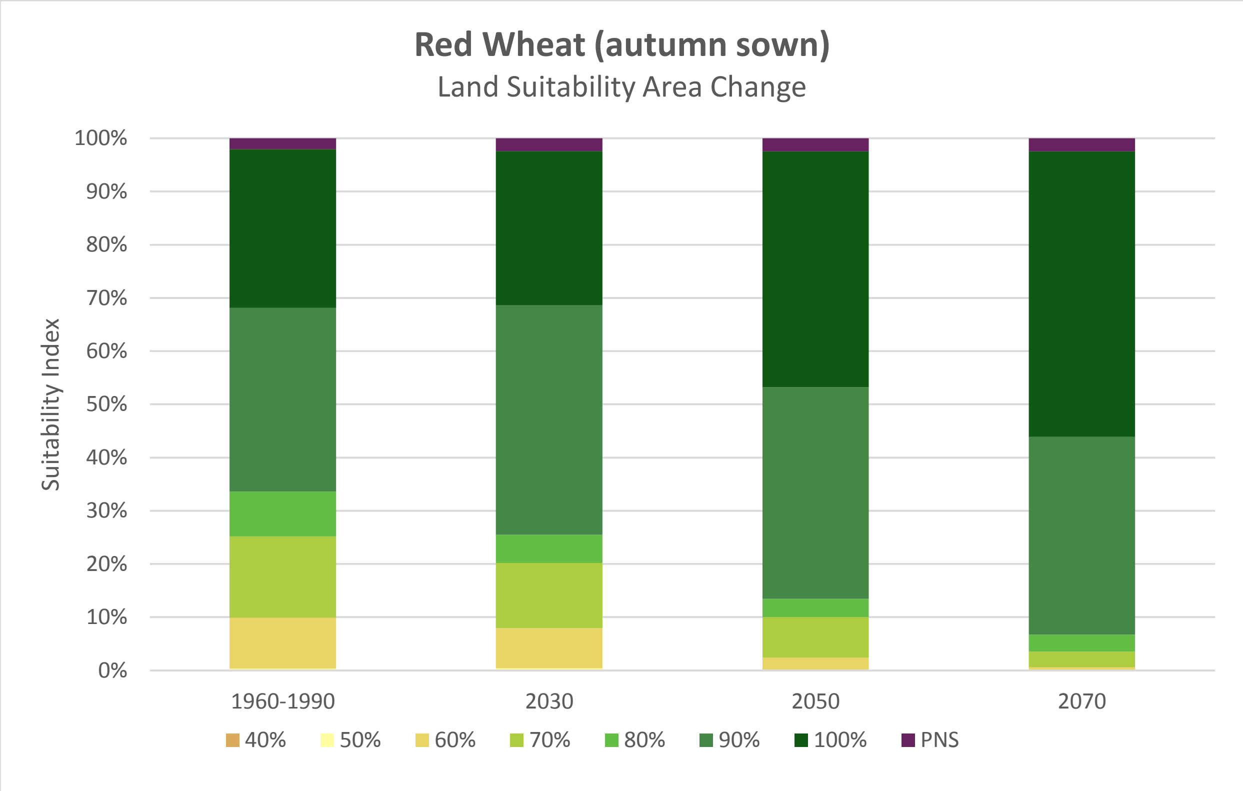

Figure 15 – Land Suitability Area Change for Autumn Sown Red Wheat

Quinoa (spring sown)

Scientific name: *Chenopodium quinua*
Common name: Quinoa, Bolivian cultivars
Family: Amaranthaceae

Quinoa is a grain crop native to Andes region of South America, being grown in a range of altitudes, climate and soil conditions. It belongs to the same family as Sugar Beet, Table Beet Spinach and Swiss Chard (Vogel et al. 2008). The world prices of quinoa have increased substantially in recent years (Foster et al. 2005). The main exporters are still South American countries Peru, Bolivia, Chile and Ecuador, but a number of European countries have been increasing their share in the world production since 2010 (Vogel et al. 2008; Foster et al. 2005; Advisory 2013). The largest producer of Quinoa in Australia is in Northern Tasmania, but cropping trials have also been successful in Western Australia. Figure 16 shows details of Quinoa's phenology and cultivation as applied in the primary production areas of South America with identical growing season specifications as for Australia.

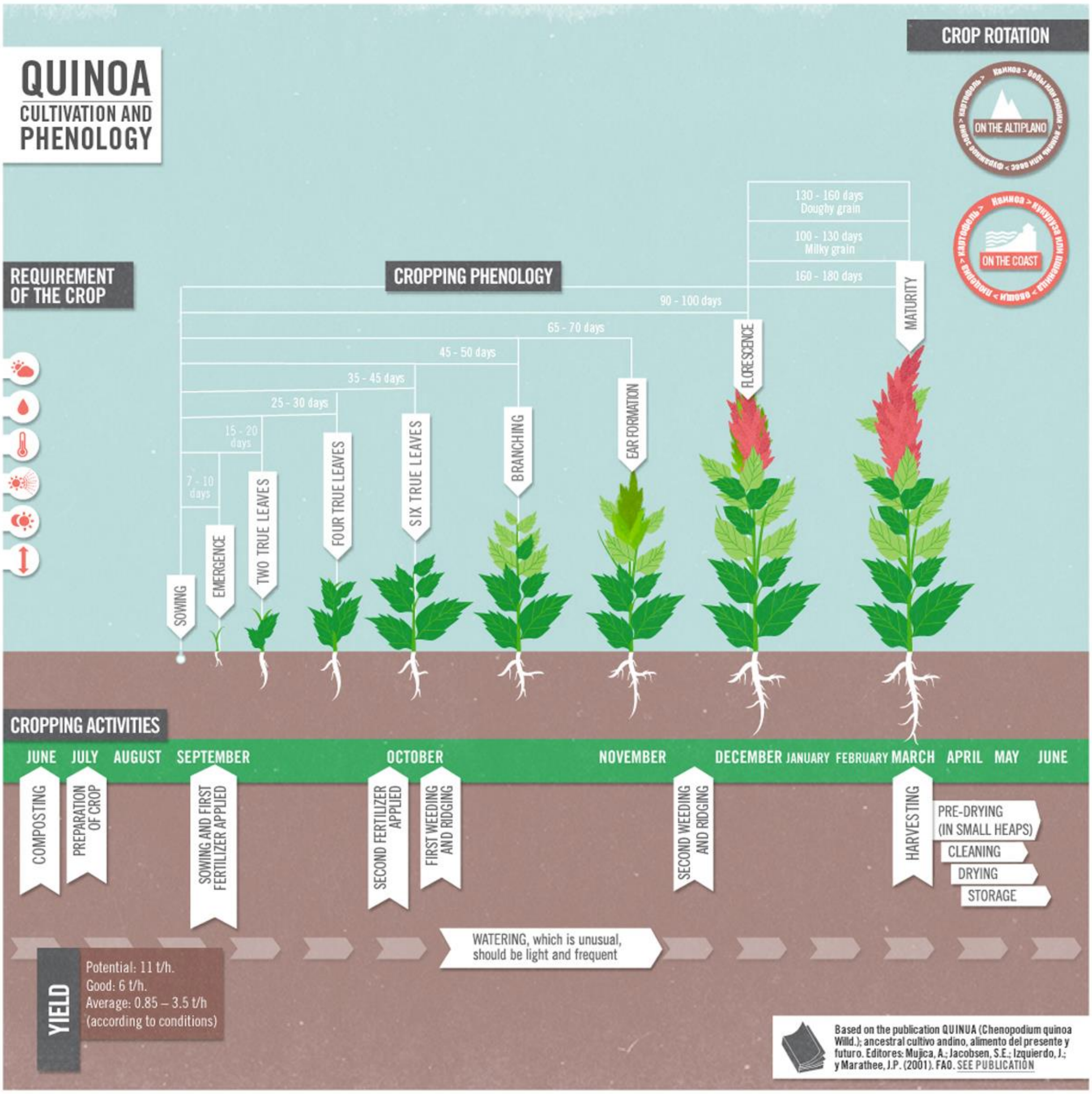

Figure 16 – Quinoa: Cultivation and Phenology (Source: Quinua.pe, 2001) (Angel Mujica et al. 2001)

Quinoa is grown in multiple agroecological zones with very different climate and soil conditions and corresponding yields ranging from 1.5 t/ha to 11 t/ha (Bojanic 2011). It withstands temperatures from -4°C to 38°C and is highly water efficient, withstanding rainfall as low as 100 – 200 mm and as high as 1000 – 2000 mm per growing season (with drainage constraints due to low waterlogging tolerance) (Mina & Bazile, D.; Bertero, D. ; Nieto 2014; Bojanic 2011; Rural Industries Reserach and Development Corporation 2014). Ideal temperatures are 10°C – 18°C during germination and 15°C – 23°C for maturing (Mina & Bazile, D.; Bertero, D. ; Nieto 2014; Bojanic 2011). Quinoa can therefore be grown in both winter and summer, as modelled below. Based on the available trials in WA, it is vital for farmers to select an appropriate variety for their location (general agroecological zones suited for quinoa are in Table 2). Quinoa prefers loamy soil texture with good drainage. Neutral pH (H_2O) 5.5 – 8.5 is optimal, but plants tolerate acidic pH 4.5 to alkaline pH 9.5 soils (Apaza et al. 2015; Rural Industries Reserach and Development Corporation 2014; Mina & Bazile, D.; Bertero, D. ; Nieto 2014).

Table 2 - Precipitation and temperature requirements of Quinoa cultivars in different agroecological zones

DE VALLE	700 – 1500 mm	3°C minimum
DE ALTIPLANO	400 – 800 mm	0°C minimum
DE LOS SALARES	250 – 400 mm	-1°C minimum
DE NIVEL DEL MAR	800 – 1500 mm	5°C minimum
YUNGAS	1000 – 2000 mm	11°C minimum

(Source: Mina, D. et al 2014) (Mina & Bazile, D.; Bertero, D. ; Nieto 2014)

The model for spring sown quinoa is based on Bolivian cultivars grown in WA with low rainfall requirements of 350 – 450 mm per growing season. The plants are sown in mid-spring and harvested in mid-autumn, with temperatures of 8°C - 27°C. Due to waterlogging issues in the catchment, a rainfall cut-off was set at 600 mm. Soil texture, pH and drainage are the most limiting soil factors. The land suitability model projects high suitability on 90% of the catchment area, with little change into the future, as demonstrated in Figure 18 and Figure 17. Medium suitability is in areas with poor drainage or soils of heavy and sandy textures. Slight reduction in suitability in the south or the catchment is due to projected increase in summer rainfall.

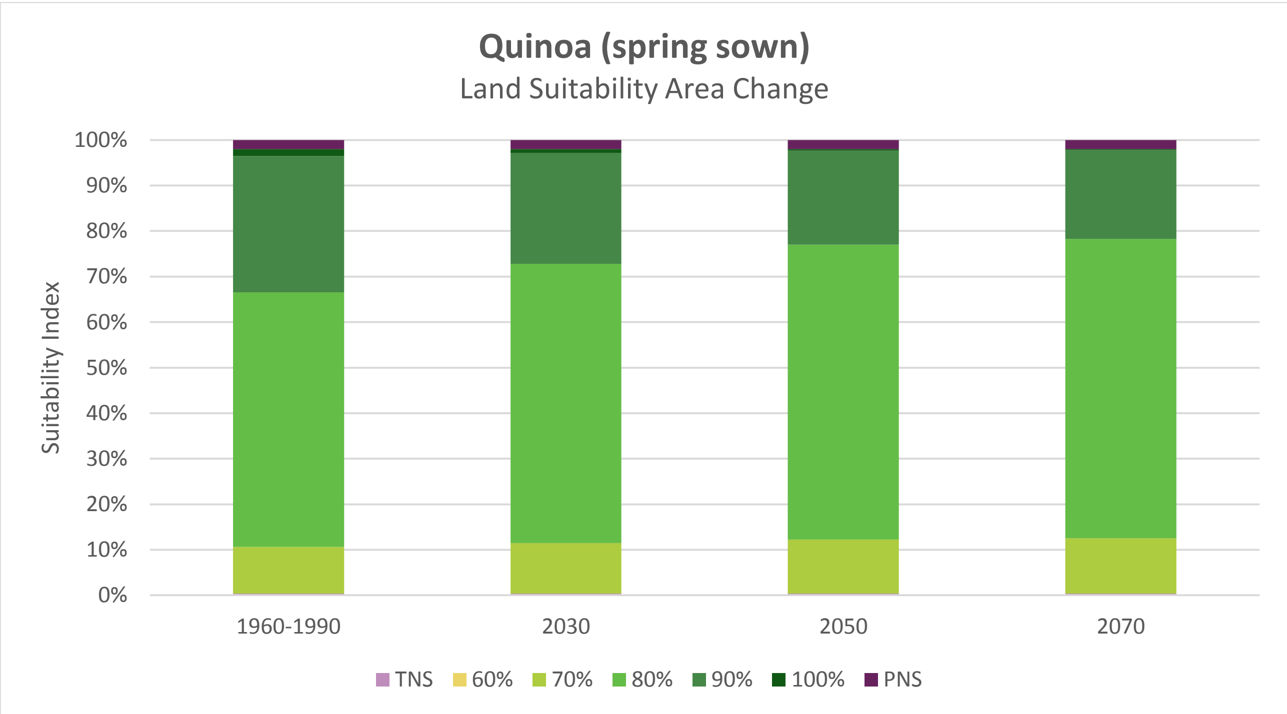

Figure 17 – Changed in land suitability area of spring sown quinoa

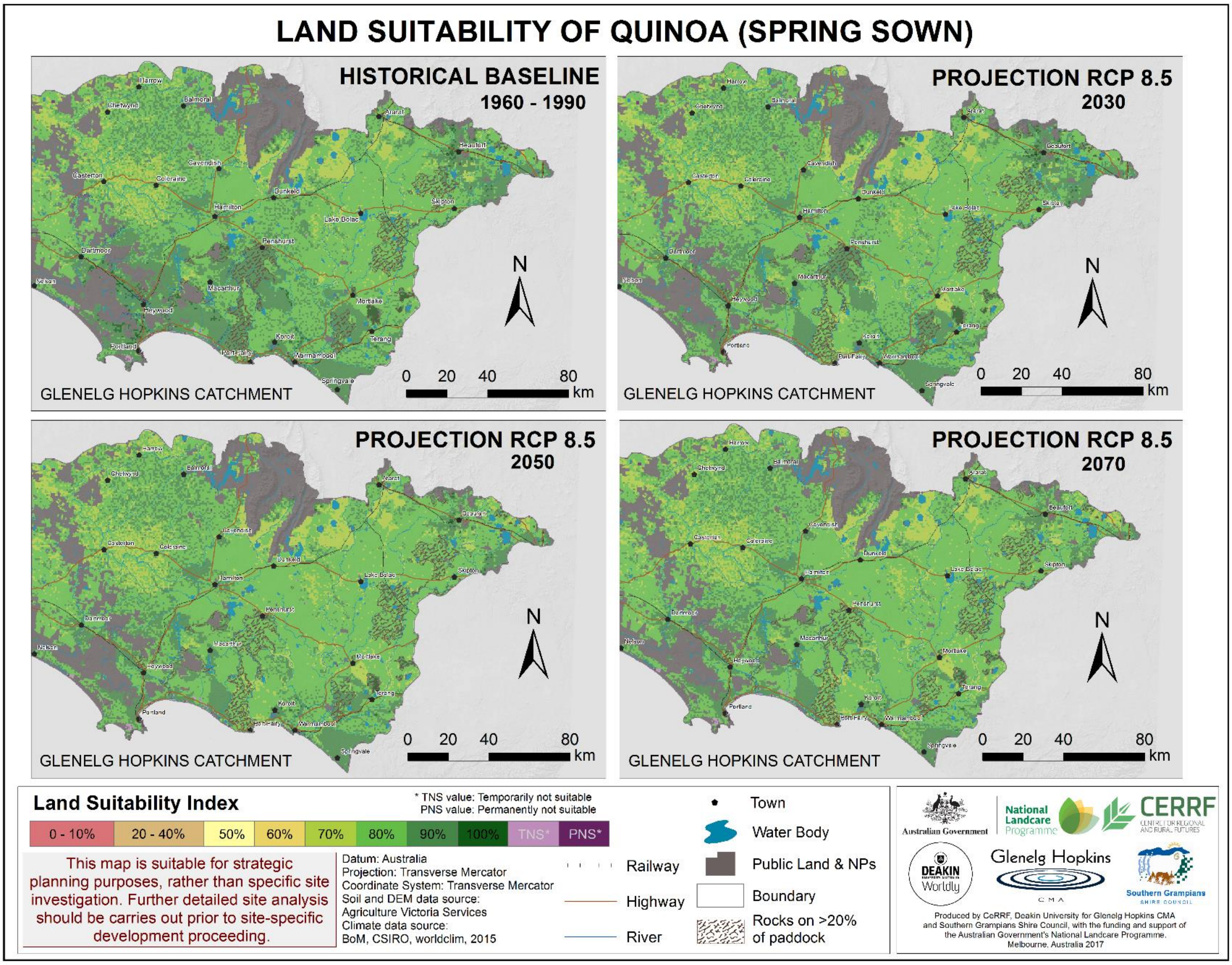

Figure 18 – Spring sown quinoa land use suitability maps for baseline of 1960-1990 and climate projections RCP 8.5 for 2030, 2050 and 2070

Quinoa (autumn sown)

Scientific name: *Chenopodium quinua*
Common name: Quinoa, Bolivian cultivars
Family: Amaranthaceae

The model for autumn sown quinoa has been based on Peruvian cultivars requiring higher rainfall of 450 – 600 mm per growing season, and cooler temperatures of 4°C - 15°C for germination and growth. Due to waterlogging issues in the catchment, a rainfall cut-off was set at 700 mm. Soil texture, pH and drainage are the most limiting soil factors. The land suitability model projects high suitability on approximately 85% of the catchment area, with an increase in the south-west of the catchment but a decrease in the north-east, demonstrated in Figure 19 and Figure 20. Projected winter rainfall reduction improves the conditions for quinoa plants in the south, but has adverse effect in the north. An overall increase in winter temperature also improves suitability and potential yields set at conservative 2 – 4 t/ha. Medium suitability is in areas with poor drainage or soils of heavy and sandy textures.

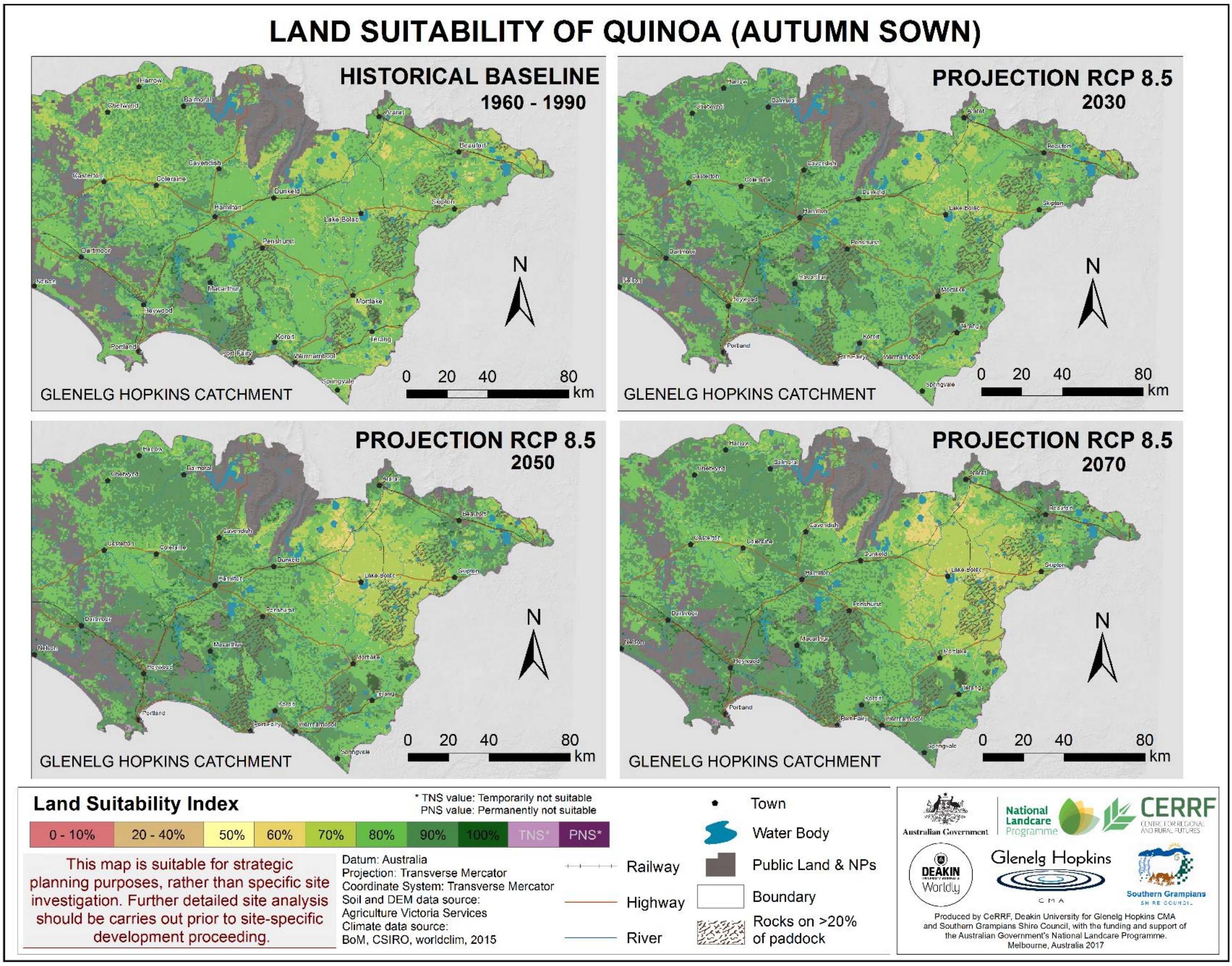

Figure 19 - Autumn sown quinoa land use suitability maps for baseline of 1960-1990 and climate projections RCP 8.5 for 2030, 2050 and 2070

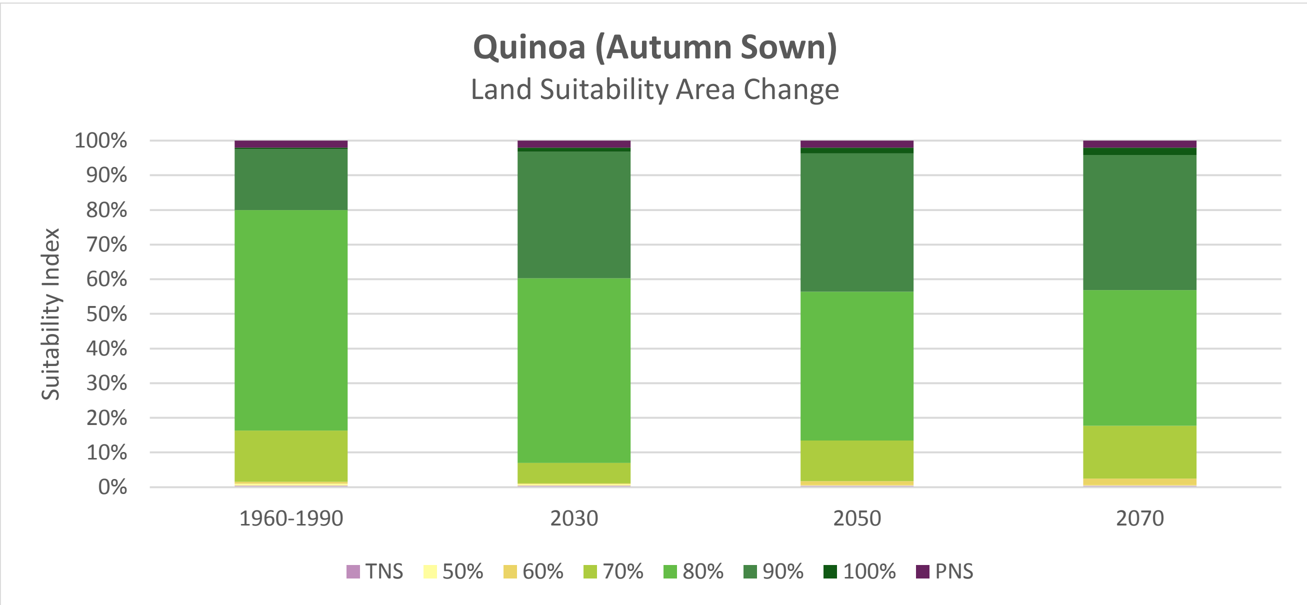

Figure 20 – Area Change in Land Suitability of autumn sown Quinoa

B. Pulses

Chickpeas (autumn sown)

Scientific name: *Cicer arietinum*
Common name: Chickpeas
Family: Fabaceae

Chickpea is a nitrogen fixing pulse crop and is therefore highly beneficial for soil health when incorporated into the existing cereal crop rotation (Victorian Winter Crop Summary 2016; Jenkins & Brill 2011). Chickpea production in Victoria has recently dropped, as shown in Figure 21, but is likely to increase due to low prices of cereals and rise in demand from South-east Asian countries (Pulse Australia 2016).

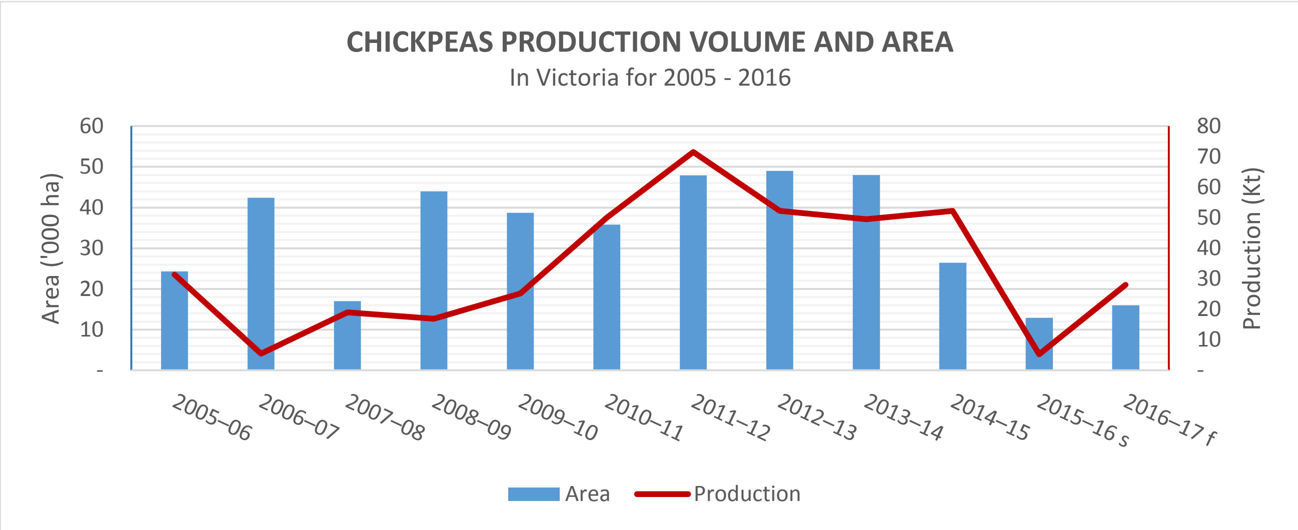

Figure 21 – Chickpea production volume and area in Victoria for 2005 – 2016 (Source: ABARES, 2017)

Traditionally, chickpeas have not been a part of the south west Victorian winter crop rotation due to their high sensitivity to waterlogging, soil acidity and low temperatures. Projected shift in future temperatures has the potential to improve growing conditions to suit chickpeas in parts of the catchment with adequate soil parameters. Based on National Variety Trials done by the GRDC initiative around Horsham, Kabuli Chickpeas have been modelled as a cold season pulse crop sown in late autumn with target yield of 2-4 t/ha (GRDC: Grains Research & Development Corporation 2017c). Rainfall requirements are 350 – 450 mm. The plant is relatively drought resistant due to its long taproot but has low tolerance to waterlogging (Corp et al. 2004; GRDC: Grains Research & Development Corporation 2016). Significant limitation for growing chickpeas in the area are winter temperatures. Mean daily temperatures below 15°C causes flower drop and over 35°C result in flower abortion, leading to yield reduction(VIC & Pulse Australia 1990; Anwar et al. 2003). Crop growth is limited due to sub-optimal temperatures in winter, but accelerates with warmer weather in spring (VIC & Pulse Australia 1990). Slope should not exceed 25%, depending on the risk of soil erosion and machinery access, but also run-off accumulation at the low-lying areas. Chickpeas thrive on well-drained loam to clay soils with neutral pH (H_2O) of 6-8 (GRDC: Grains Research & Development Corporation 2016; VIC & Pulse Australia 1990; Corp et al. 2004). It will not grow on acid or saline soils with poor drainage.

Validation feedback received from farmers pointed out soil pH, drainage and waterlogging as the most significant factor impacting chickpea production. Due to potential waterlogging issues in the south of the catchment, rainfall cut-off has been introduced into the LSA model, radically decreasing suitability index of areas where seasonal rainfall reaches over 550 mm. Since chickpeas are harvested very close to the ground, a rockiness overlay has also been included on the suitability maps in Figure 22. The insufficient winter temperatures would suggest the potential for chickpeas to be grown as a summer crop. Consultation of local cropping farmers pointed out the low reliability of spring break rainfall needed to accumulate a sufficient amount of soil moisture for successful plant germination. This model therefore treats chickpeas as a winter crop.

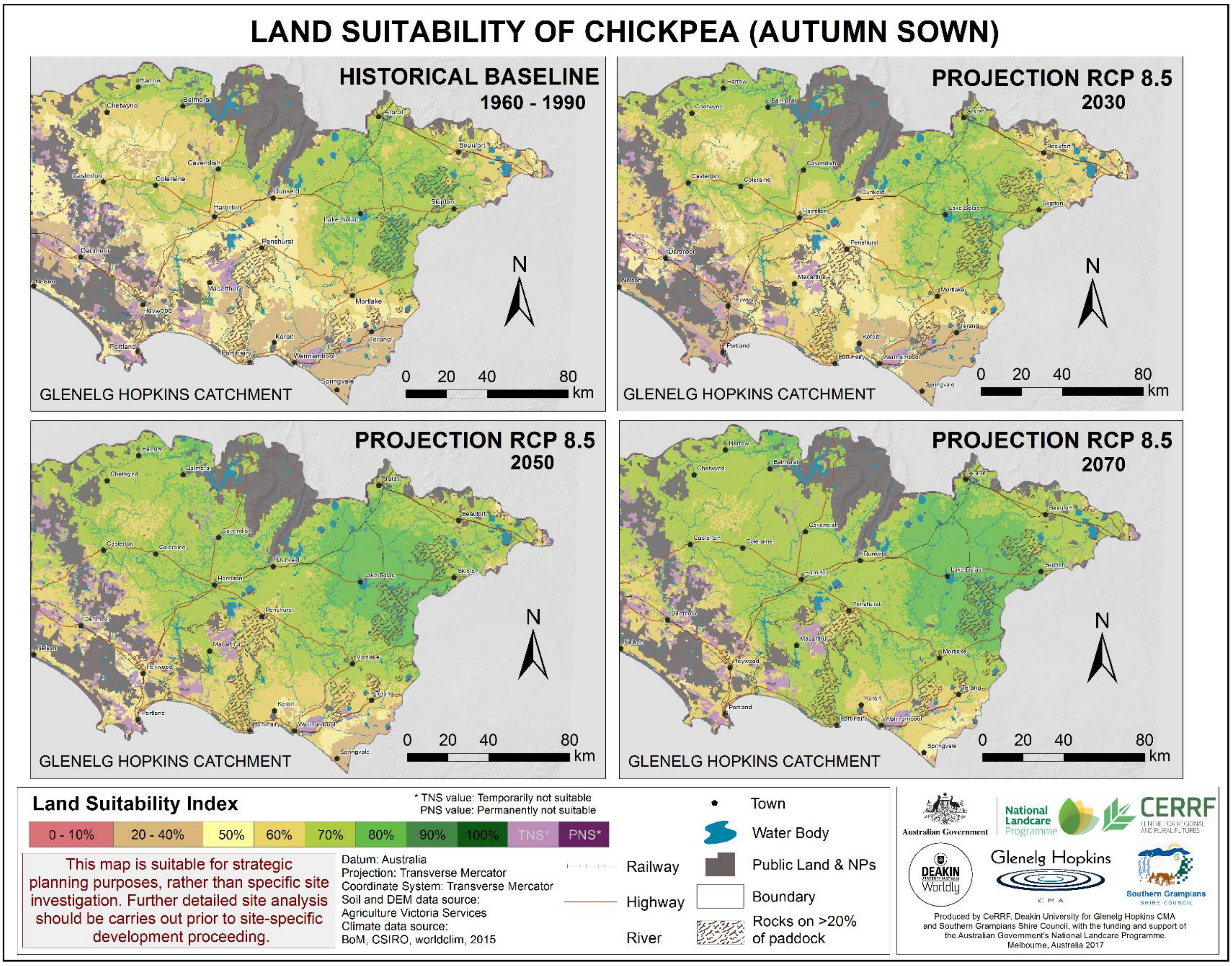

Figure 22 - Autumn sown chickpeas land use suitability maps for baseline of 1960-1990 and climate projections RCP 8.5 for 2030, 2050 and 2070

Land suitability model of autumn sown chickpeas shows a low to medium suitability for baseline. A medium suitability of 70% is limited to the traditional cropping areas of the catchment with lowest rainfall. Temperatures across the catchment are projected to increase and precipitation is likely to decrease, improving the climate suitability of chickpeas in the area. The overall suitability is predominantly driven by rainfall and soil parameters, which results in 10% of the area falling into the Temporarily Not Suitable category of pH (H_2O) lower than 5.5, and 70% of the catchment having medium suitability by 2070 (viz. Figure 23).

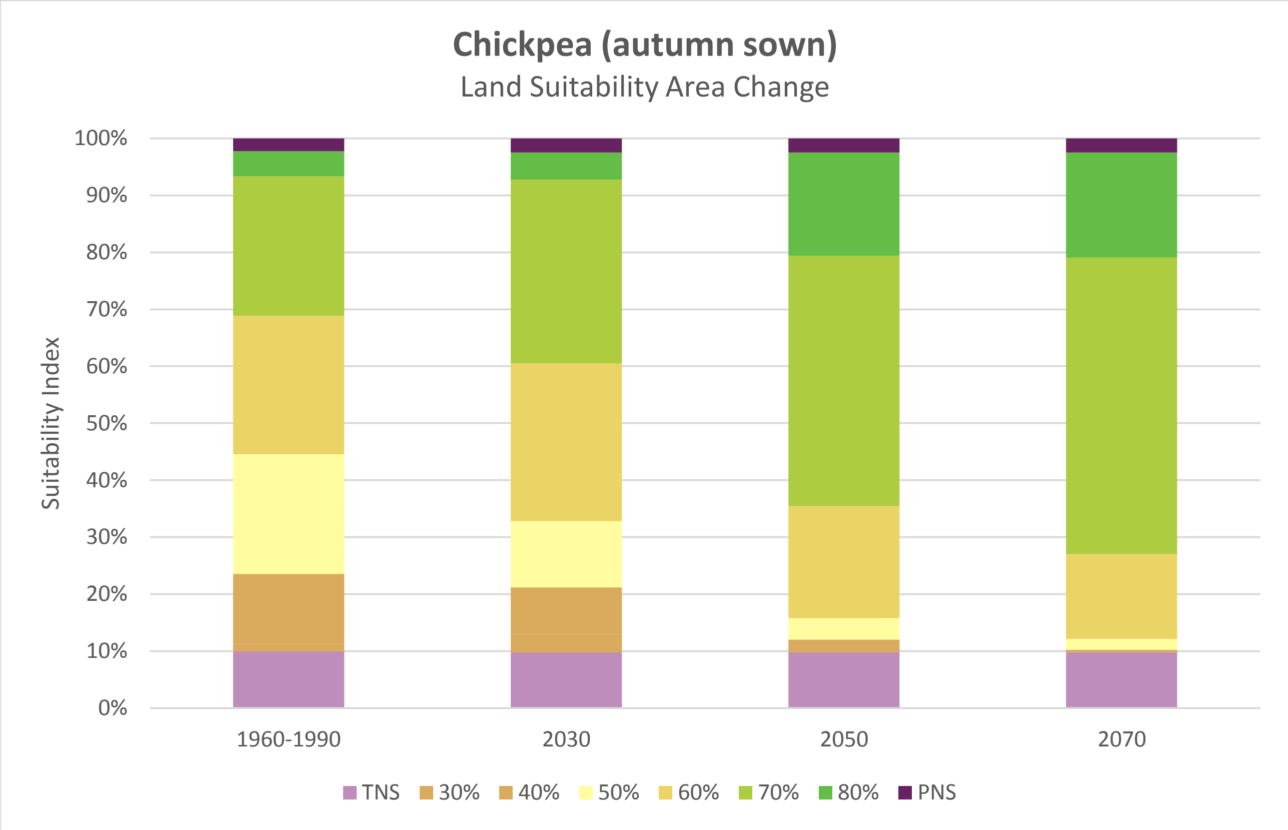

Figure 23 – Autumn sown chickpeas land suitability change in area percentage

Faba Bean (autumn sown)

Scientific name: *Vicia Faba*
Common name: broad/fava/faba/field bean
Family: Fabaceae

Faba bean is a nitrogen fixing pulse crop and is therefore highly beneficial for soil health when included in the existing cereal crop rotation(The State of Victoria Department of Environment and Primary Industries 2013; Matthews & Marcellos 2003). Chickpea production in Victoria has been steadily growing with a recent drop, as shown in Figure 24, but is forecasted to increase due to low prices of cereals (Pulse Australia 2016). Due to previous crop failures of faba beans in the Glenelg Hopkins catchment, their incorporation into the crop rotation is likely to be slower than in the rest of Victoria.

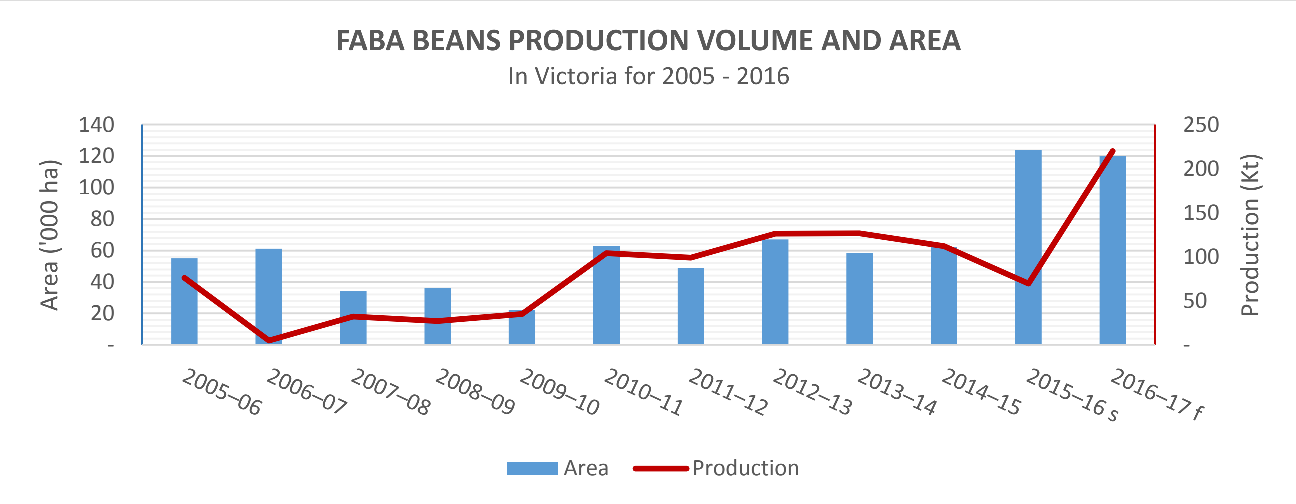

Figure 24 – Faba bean production volume and area in Victoria for 2005 – 2016 (Source: ABARES, 2017)

Based on National Variety Trials done by the GRDC initiative around Horsham, Kaniva, Wonwondah and Lake Bolac, faba bean has been modelled as a cold season pulse crop sown in mid-autumn with target yield of 3-6 t/ha (GRDC: Grains Research & Development Corporation 2017c). Rainfall requirements are above 400 mm, with a rainfall cut-off at 550 mm. The plant is more resistant to waterlogging than chickpeas, but is prone to disease and pest infestation in in high-rainfall areas(GRDC: Grains Research & Development Corporation 2017a; The State of Victoria Department of Environment and Primary Industries 2013; Matthews & Marcellos 2003). Optimal growing temperatures are 15°C – 20°C, but frost is tolerated(The State of Victoria Department of Environment and Primary Industries 2013; Matthews & Marcellos 2003). Flowering will abort at temperatures over 30°C (Matthews & Marcellos 2003), cooler spring conditions are therefore ideal for successful pod development(The State of Victoria Department of Environment and Primary Industries 2013). Slope should not exceed 25%, depending on the risk of soil erosion and machinery access, but also run-off accumulation at the low-lying areas. Soils with limited soil depth, very light and sandy in texture and low pH ($CaCl_2$) <5.2 are to be avoided, but they have been successfully grown on pH of 4.6 but with low Aluminium content (GRDC: Grains Research & Development Corporation 2017a; Matthews & Marcellos 2003). Faba beans prefer loamy clays that hold moisture.

Validation feedback from farmers emphasised high acidity and sodicity as limiting factors for faba beans. It also stressed the importance of heavier textured soils that retain moisture but are also sufficiently drained. The issue of pests and disease spread during conditions with excess moisture is substantial, but could not be included in this model. Similarly to grains and chickpeas, a rockiness overlay has also been included on the suitability maps presented in Figure 25.

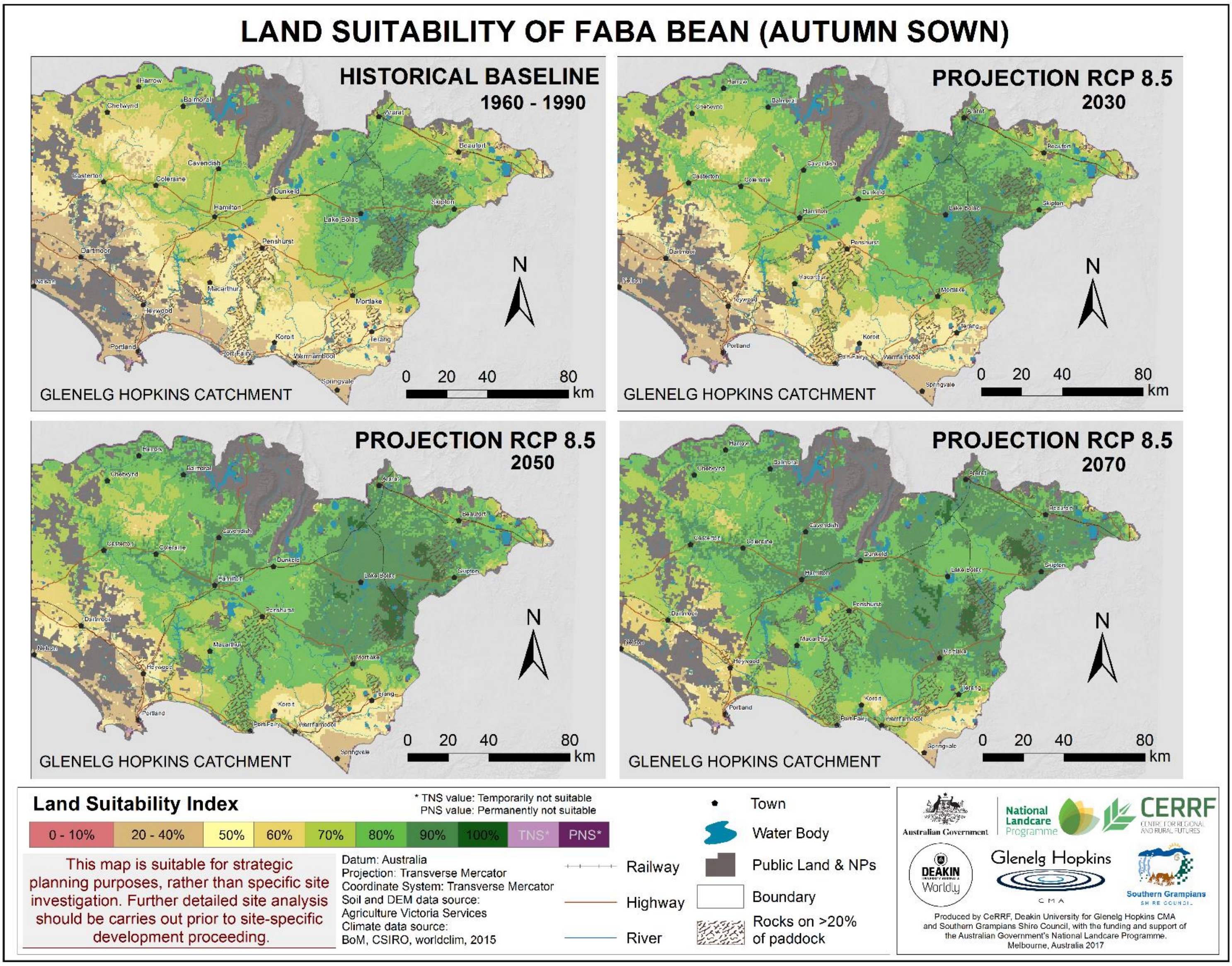

Figure 25 - Autumn sown faba bean land use suitability maps for baseline of 1960-1990 and climate projections RCP 8.5 for 2030, 2050 and 2070

Baseline suitability of faba beans shows low to medium suitability across majority of the catchment. Light textured soils in the north-west, pH and drainage are the main limiting soil factors. Growing season temperatures remain within the optimal range and the likely decrease in winter rainfall increases the overall suitability in the region. Due to those climatic trends, faba beans are projected to be highly suitable (between 80 and 90% Land Suitability Index) on approximately 70% of the catchment area by 2070, as shown in Figure 26.

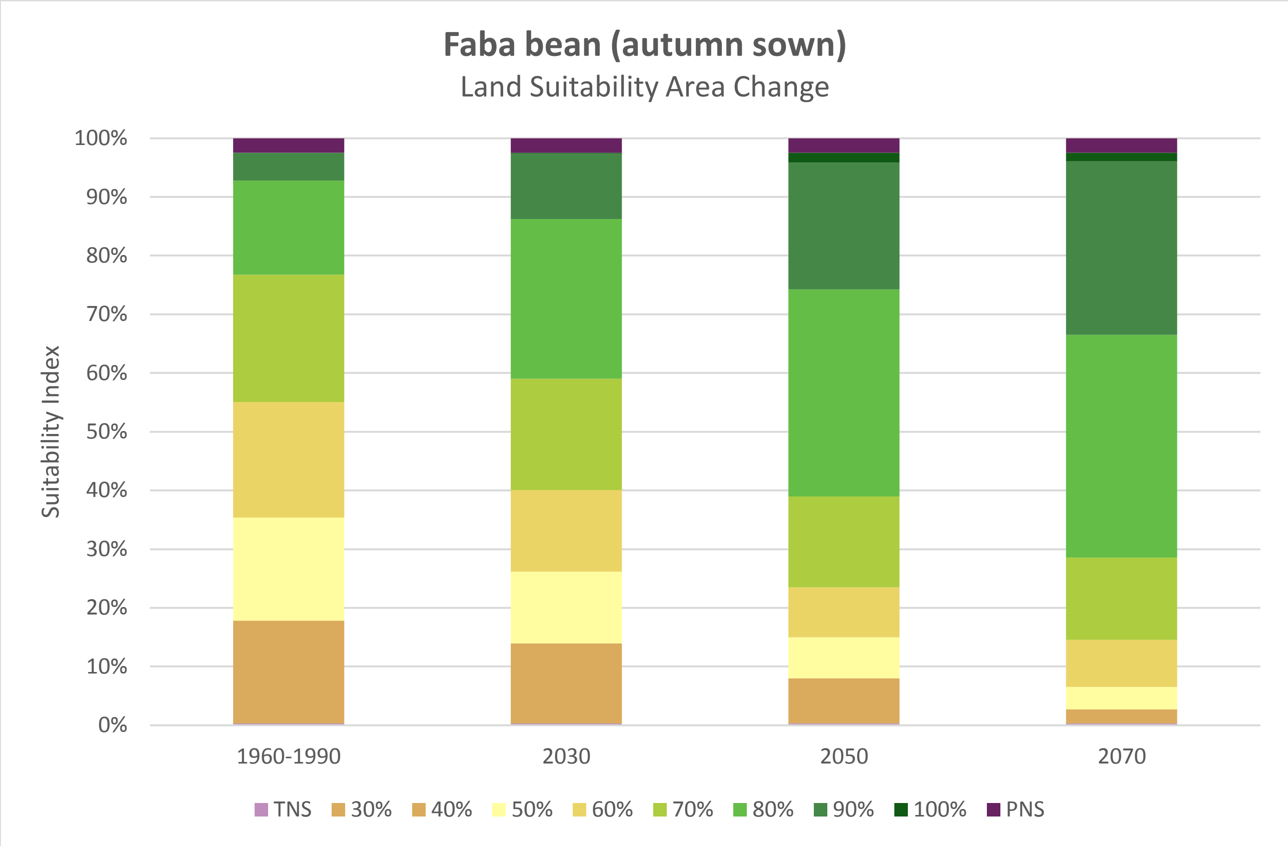

Figure 26 – Land suitability area change for autumn sown faba bean

C. Oil Crop Plants

Mustard Seed (autumn sown)

Scientific name: *Brassica Juncea*
Common name: Brown/Indian mustard
Family: Brassicaceae

Mustard seed belongs to brassicas and is very similar to canola, although less common. As demonstrated in Figure 27, production along with productivity of canola is likely to increase due to projected commodity prices (Rural Bank Ltd & Bendigo and Adeleide Bank Limited 2016). Mustard seed as a condiment mustard has a rather limited market in Australia, but as a drought resistant oil seed, it can present a viable option as a meal quality oil or biofuel.

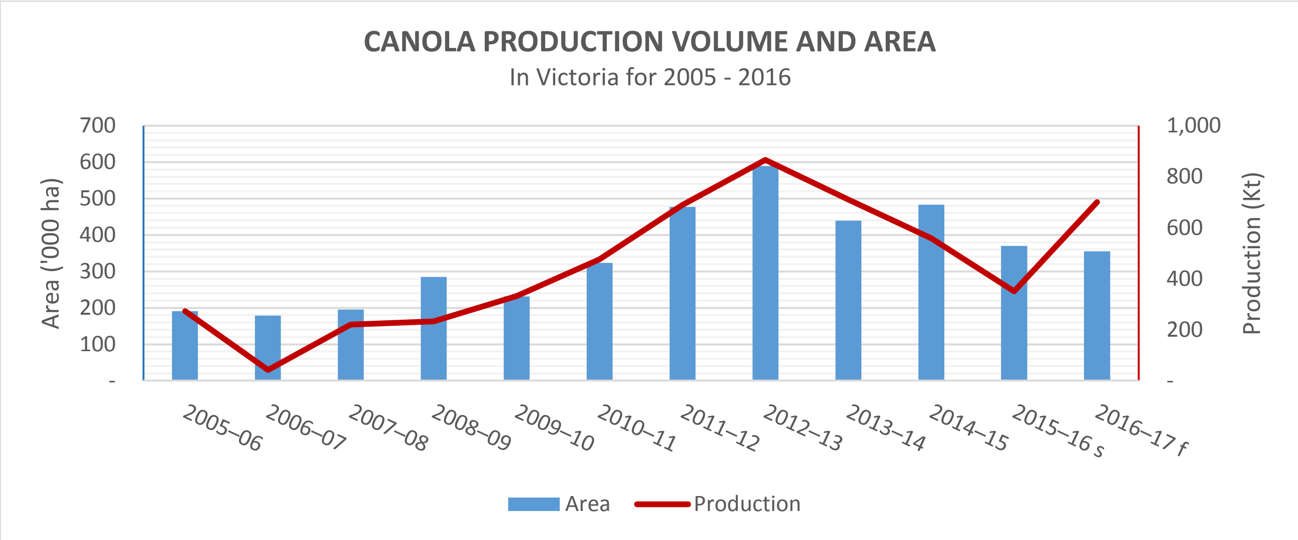

Figure 27 – Production volume and area of canola in Victoria for 2005 – 2016 (Source: ABARES, 2017)

There are multiple varieties of mustard. This model is based on *Brassica Junacea* or Indian mustard, a close relative of canola that has been bred as a heat and drought resistant alternative (Norton et al. 2009), yielding 2 – 3 t/ha based on variety evaluation experiments at the Mallee Research Station and Minnipa Research Centre(Castleman 1994). It is suited to areas with rainfall below 350 mm and can be sown mid- to late-autumn(Norton et al. 2009). Temperature requirements are similar to canola, 10°C – 25°C, but can withstand maximum heat stress of up to 32°C without having adverse effects on the quality of oil during flowering and pod fill (canola's maximum is 26.5°C without an impact on the oil composition)(Johnston et al. 2002; Edwards & Hertel 2011; Chauhan et al. 2009). Slope should not exceed 25%, depending on the risk of soil erosion and machinery access, but also run-off accumulation at the low-lying areas. Junacea canola, or mustard seed, grows on most soil types but prefers medium and lighter textured substrate, tolerating moderately acidic to alkaline soils with pH ($CaCl_2$) above 5.0 and below 8.5 (Norton et al. 2009; Hunt & Norton 2011). It is sensitive to waterlogging and sodicity levels(Norton et al. 2009; Holland et al. 1999; Edwards & Hertel 2011).

Validation feedback confirmed higher heat and drought tolerance and suggested planting at the same time or later than canola. It also identified soil type and drainage as important factors influencing soil suitability in relation to waterlogging susceptibility.

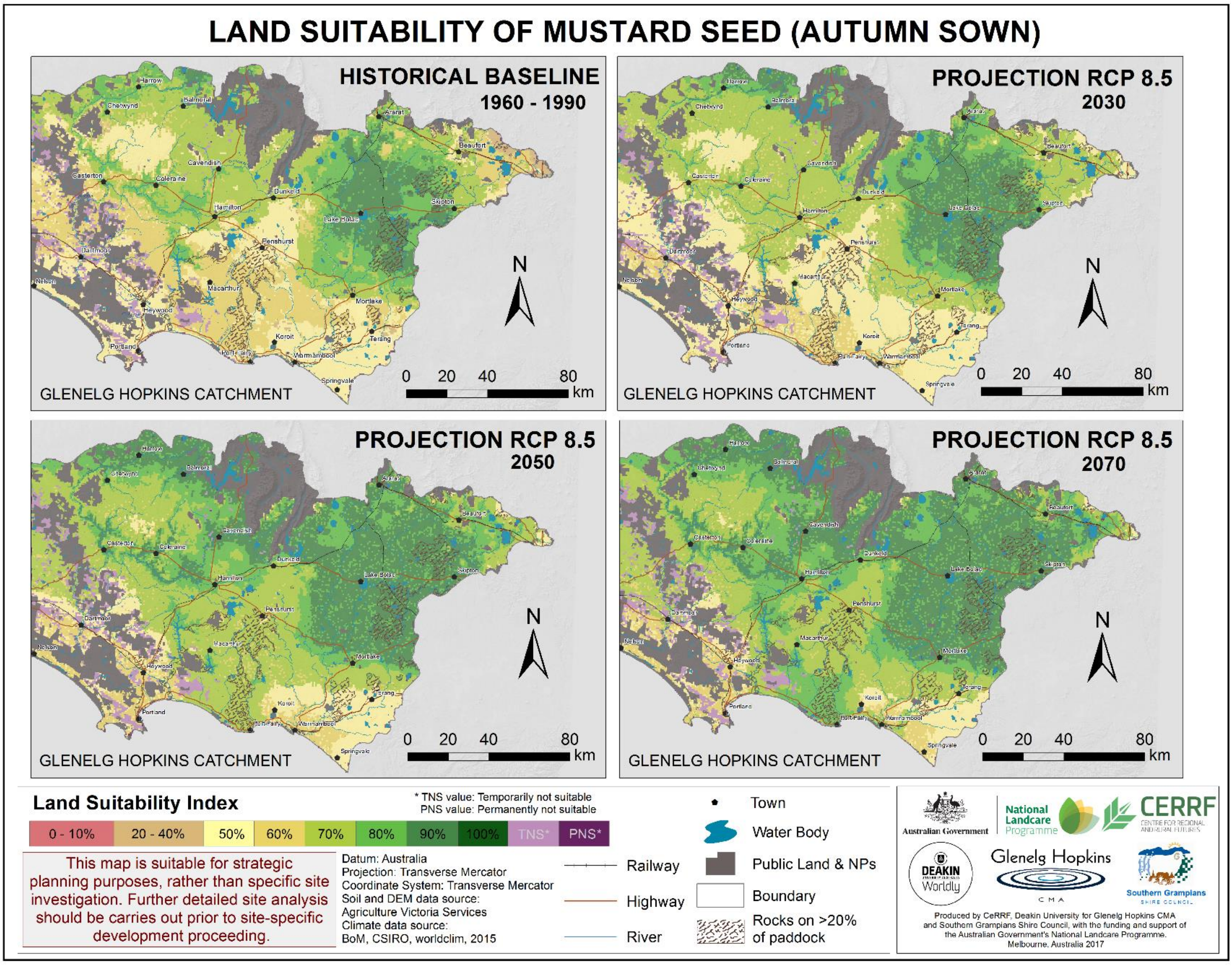

Figure 28 - Autumn sown mustard seed land use suitability maps for baseline of 1960-1990 and climate projections RCP 8.5 for 2030, 2050 and 2070

Figure 28 shows highest baseline suitability for mustard seed in the driest area of the catchment (the traditional cropping region in the north-east corner of Glenelg Hopkins), indicating high influence of rainfall on suitability. The high suitability area increases from 20% of the catchment for 1960-1990 to over 50% in 2070, as demonstrated in Figure 29. It follows a similar pattern to barley and red wheat by suggesting a spread of cropping further south. Drainage and soil type are the most significant soil factors influencing the commodity performance. Stoniness, preventing access or successful operation of machinery has also been taken into account and is presented as an overlay of paddocks with rocks on more than 20% of their area. Approximately 5% of the area fall under temporarily not suitable category due to its subsoil pH ($CaCl_2$) level below 5.

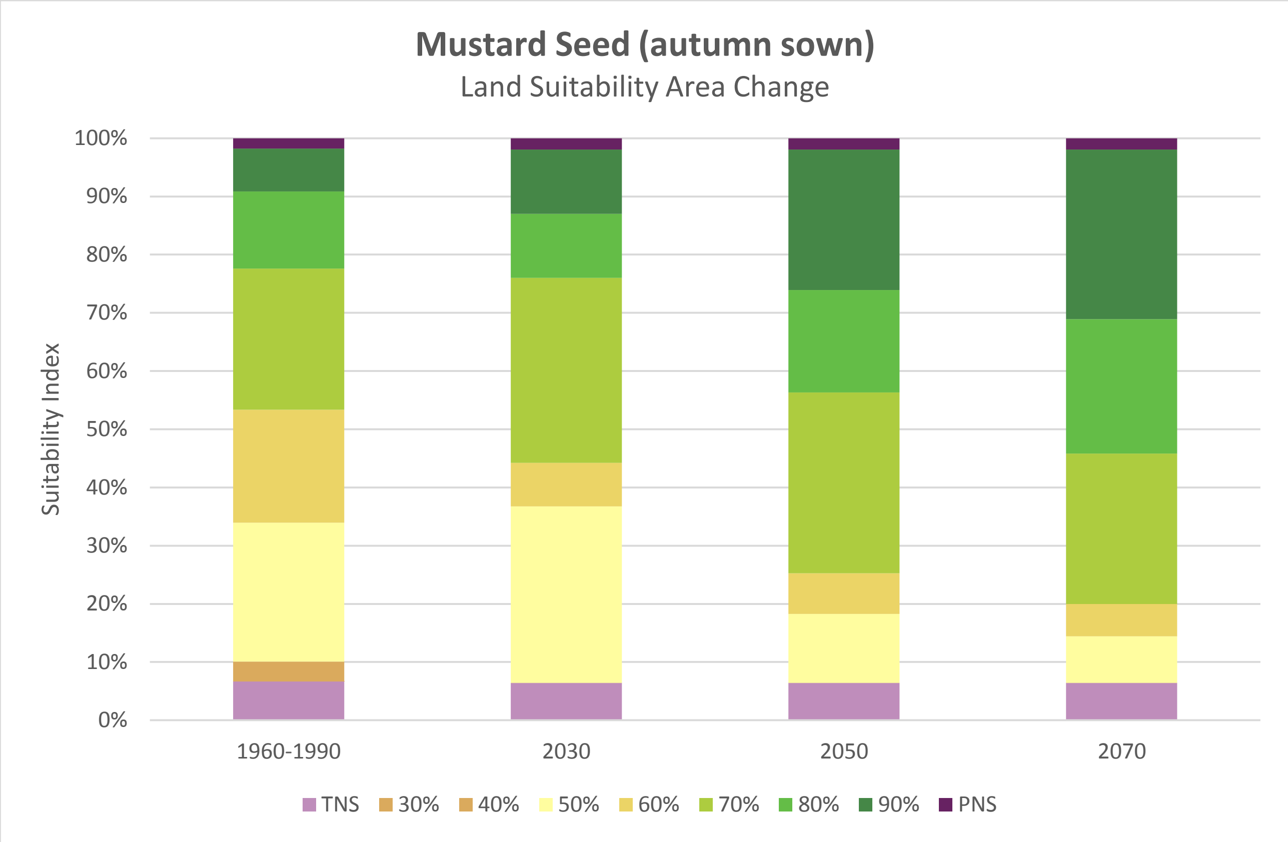

Figure 29 – Land suitability area change of autumn sown mustard seed

Sunflower Seed (spring sown)

Scientific name: *Helianthus annuus*
Common name: Sunflower
Family: Asteraceae

Sunflower is an alternative oil seed whose production in Victoria has been rather volatile, with a sharp increase in 2009/2010 season and a gradual decline since then, as demonstrated in Figure 30.

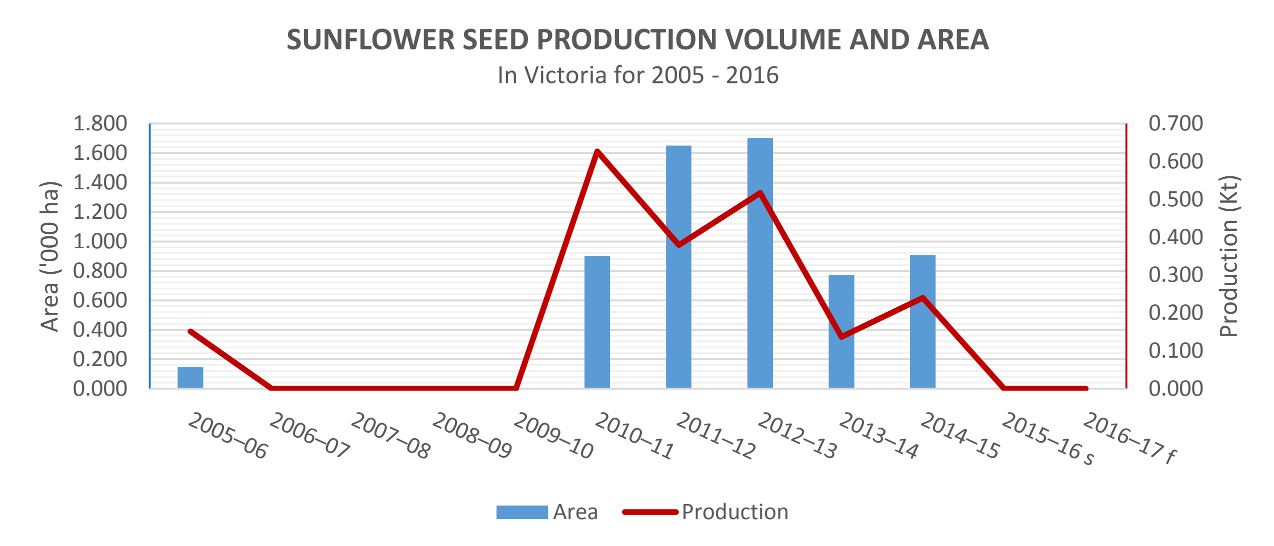

Figure 30 – Sunflower seed production volume and area in Victoria for 2005 – 2016 (Source: ABARES, 2017)

Sunflower is tolerant of both low and high temperatures. It is able to withstand longer dry periods due to its long taproot, but requires sufficient soil moisture for sowing as well as an in-season rainfall between 500 and 1000 mm (National Sunflower Association 1999; Department of Agriculture Forestry and Fisheries 2010; NSW DPI 2016). Sown in early spring, sunflowers will germinate at temperature as low as 5°C, but adequate range is between 14°C and 21°C. Optimal growth temperature is 23°C – 28°C with maximum up to 34°C without adverse effects on yield (Department of Agriculture Forestry and Fisheries 2010; GRDC: Grains Research & Development Corporation 2017b) Sunflowers grow on a range of soils from sandy loams to clays with sufficient depth (with taproot penetrating as deep as 1.5m) and water holding capacity (Department of Agriculture Forestry and Fisheries 2010; NSW DPI 2016). Ideal pH ($CaCl_2$) ranges between 4.8 and 7.5 with good drainage and low salinity (Putnam et al. 1990; Roe 2001). This model has been designed to reach yield of 1.5 – 3 t/ha based on available data from case studies in NSW (Keen & Charlesworth 2009).

Being a summer crop with high water requirements, sunflowers are best fit to the coastal, high-rainfall climate conditions of catchment, unless irrigated (viz. Figure 31). Validation feedback brought up an issue presented by a relatively long growing season of sunflowers and the traditional timing of autumn break, conflicting with the crop's harvest in May.

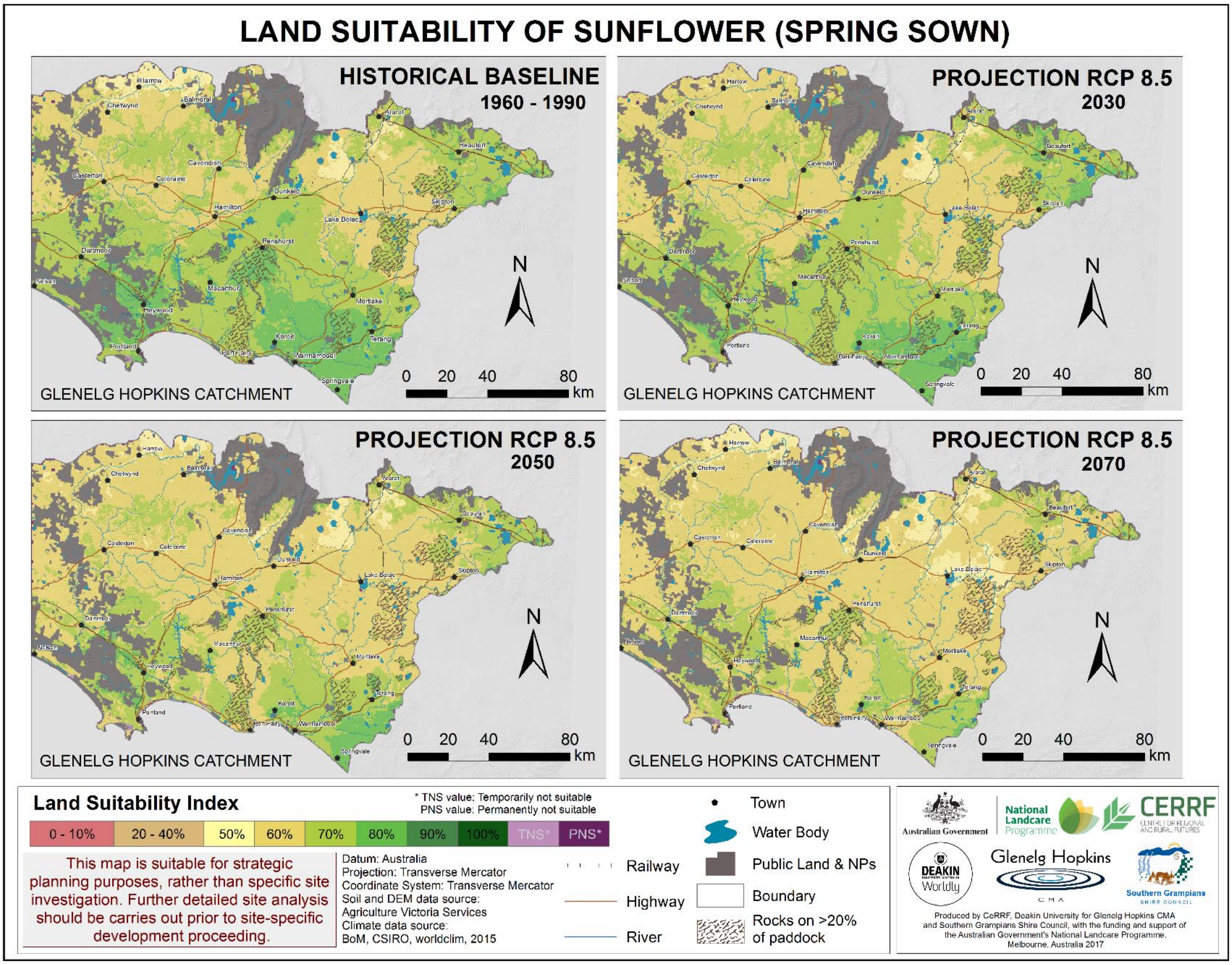

Figure 31 - Spring sown sunflower seed land use suitability maps for baseline of 1960-1990 and climate projections RCP 8.5 for 2030, 2050 and 2070

The limiting factors driving this model's suitability range are rainfall (total and timing during planting and harvest), finishing temperature, soil depth, texture and drainage. Baseline model shows sunflowers as medium to highly suitable on approximately 60% of the catchment area. Despite favourable projections of rising summer temperature, the decline in spring and autumn rainfall are likely to result in suitability decrease as shown in Figure 31Figure 32, with over 90% of the region being 60% to 70% suitable by 2070.

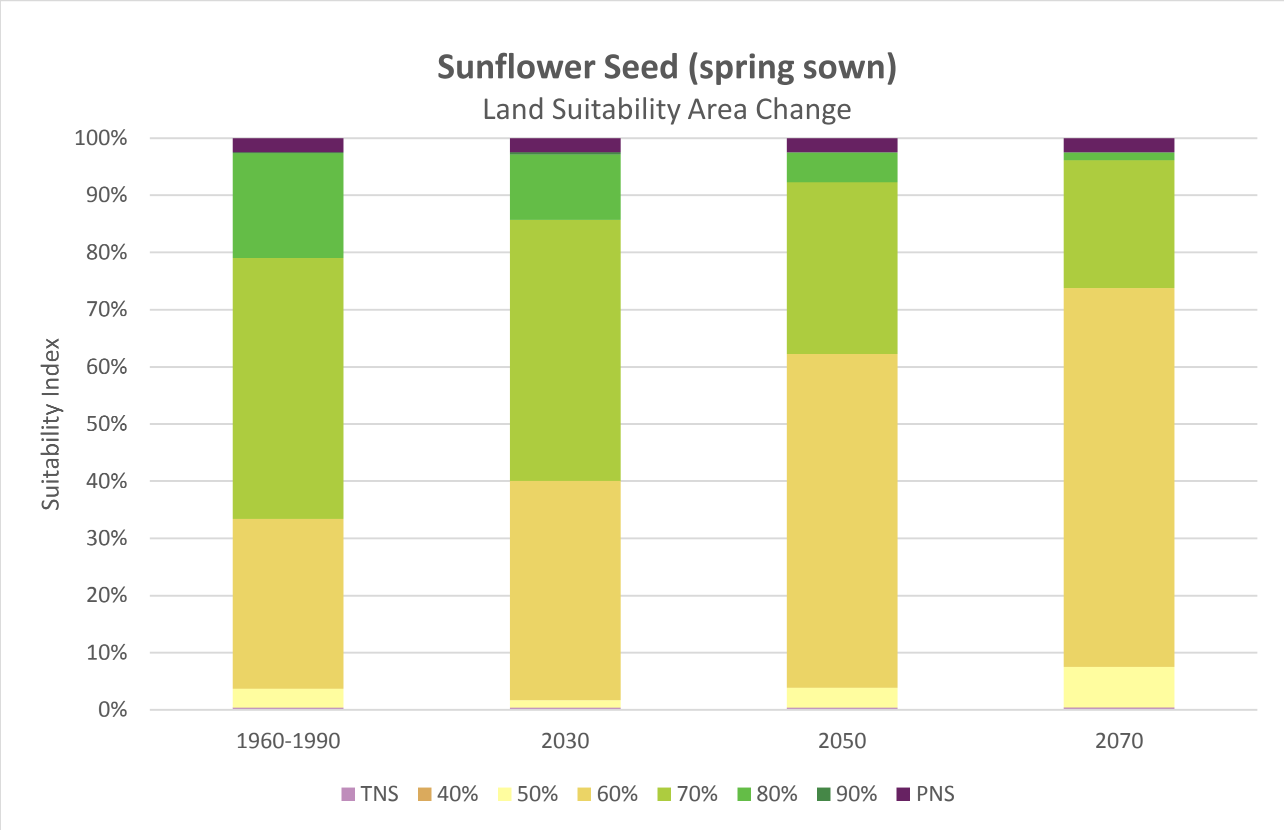

Figure 32 – Land suitability area change of spring sown sunflower

D. Fibre Crop Plants

Hemp (autumn sown)

Scientific name: *Cannabis sativa*
Common name: Hemp, industrial
Family: Cannabaceae

Industrial hemp production can be licensed in all states apart from South Australia, with each state having their own set of regulations. It is a versatile plant that can be grown for fibre, seed or oil. This model has been built around hemp production for fibre. It grows in temperate, subtropical and tropical climate, but is intolerant to frost (DPIWE Tasmania 2012b; RIRDC 2017). It prefers mild and humid conditions with rainfall of 600 – 700 mm. Ideal growing season temperatures are between 15°C and 28°C (RIRDC 2017; DPIWE Tasmania 2012b; Zurbo & Cole 2008).

Hemp prefers neutral to slightly alkaline soils (ideal pH H_2O range of 6.5 – 7.5) with good drainage(Zurbo & Cole 2008; Kaiser et al. 2014). It grows well on light to medium textured soils of clay loam or silt loam, and requires deep soil profile for its taproot that can penetrate as deep as 2m (DPIWE Tasmania 2012b; Zurbo & Cole 2008). High salinity and acidity are likely to reduce crop yields.

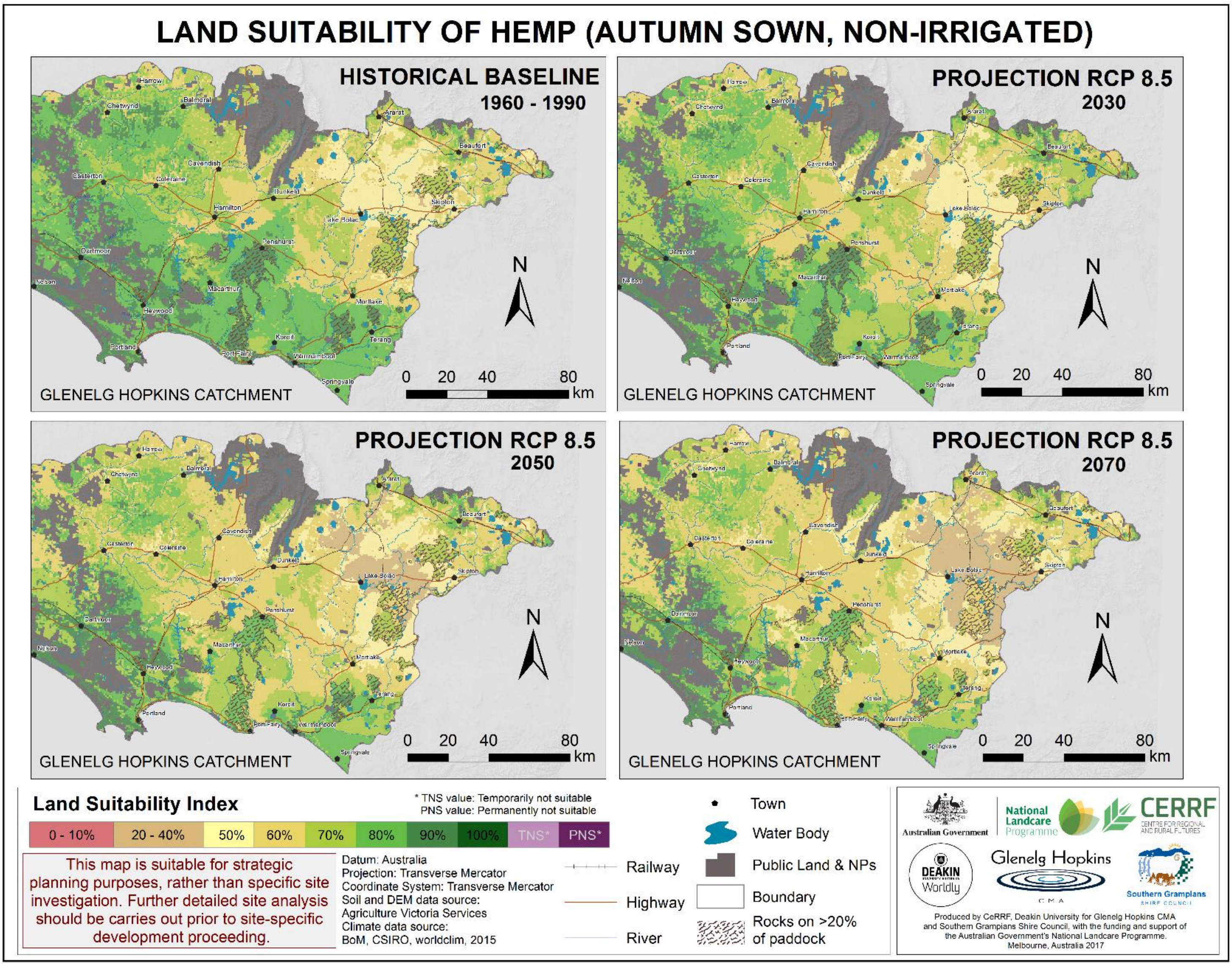

Figure 33 - Autumn sown hemp land use suitability maps for baseline of 1960-1990 and climate projections RCP 8.5 for 2030, 2050 and 2070

It has a high light requirement during its growing period, making it suitable as a summer crop(RIRDC 2017). This report modelled hemp as both a summer crop, satisfying its light and temperature requirements, and a winter crop to meet its water requirements. Figure 33 Figure 34 show models of hemp as a winter crop, with a baseline suitability of 80% - 90% on approximately half of the catchment area (predominantly the higher rainfall southern and eastern parts). The suitability is predominantly driven by rainfall since winter temperatures in the region are suboptimal, potentially limiting the growth of hemp to fibre instead of seed or oil. With the projected decline in winter rainfall, the suitability index is likely to drop significantly to approx. 25% of the catchment by 2070. Most significant soil parameters influencing the suitability model are drainage, texture and waterlogging susceptibility. An overlay of rocky patches is also incorporated into the model.

Validation feedback has been limited, stressing the importance of soil texture and depth, and excluding stony areas from production. It also pointed out the trade-off between water availability and intended use for fibre or seed.

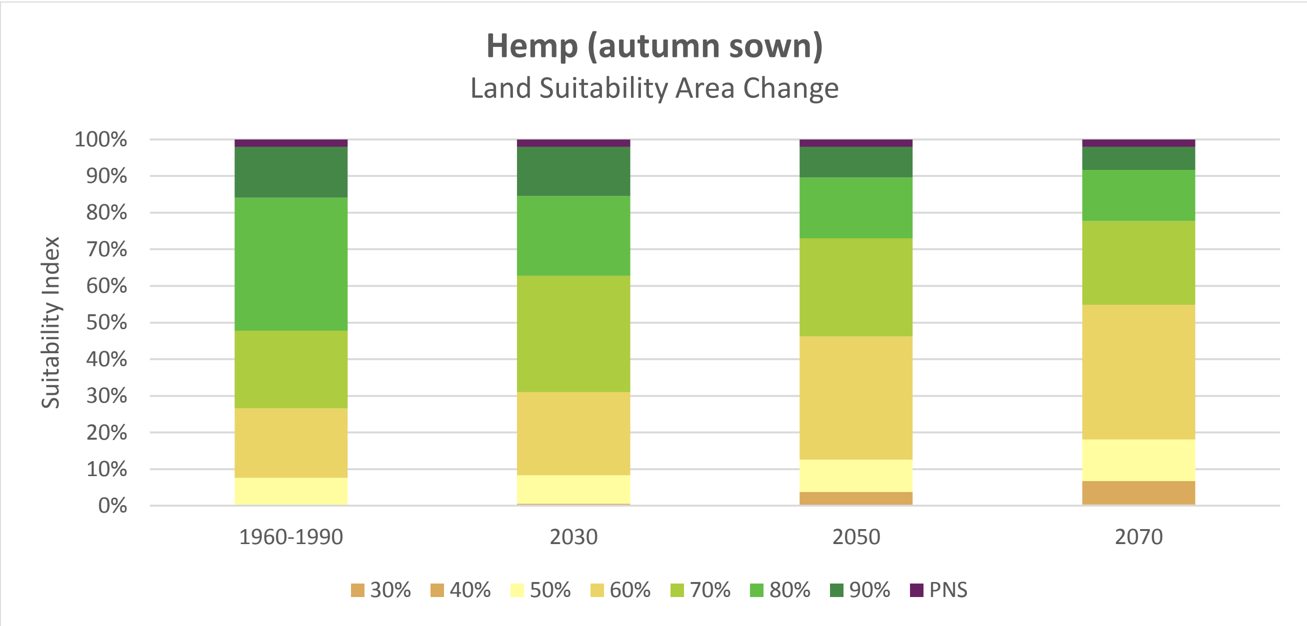

Figure 34 – Autumn sown hemp land suitability change

Hemp (spring sown)

Scientific name: *Cannabis sativa*
Common name: Hemp, industrial
Family: Cannabaceae

It has a high light requirement during its growing period, making it suitable as a summer crop(RIRDC 2017). This report modelled hemp as both a summer crop, satisfying its light and temperature requirements, and a winter crop to meet its water requirements without irrigation. As can be seen in Figure 35, Glenelg Hopkins catchment has a low baseline suitability for hemp as a summer crop due to insufficient summer rainfall. With a projected increase in summer precipitation, the suitability is likely to improve to medium by 2070 as demonstrated in Figure 36.

Figure 37 and Figure 38 show an irrigated spring sown hemp and the significant positive impact that adequate amount of available water could have on its production. Irrigation was only used in months when effective rainfall was insufficient to cover crop water requirements.

- Effective rainfall was calculated as:

  Effective rainfall [mm] (Re) = Total Rainfall – Runoff – Evaporation – Deep Percolation

- Irrigation requirement was calculated as:

  Irrigation requirement [mm] (IR) = Effective Rainfall – Commodity Water Use – Soil Water Reserve

- Water Use was conditioned as:

  If Irrigation Requirement is higher than Effective Rainfall, then the sum of Irrigation Requirement and Effective Rainfall is used. If Irrigation Requirement is lower than Effective Rainfall, then irrigation is not required and Effective Rainfall is used.

Although the baseline suitability is significantly higher for irrigated hemp than non-irrigated hemp, the median (average) suitability is likely to decrease from 79% in 1960-1990 to 71% by 2070. The climate projections predict a rapid increase of water requirements in the south of the catchment, hence decreasing hemps suitability. Likely increase in temperature and summer rainfall in the north-west results in a suitability increase by 2050, but an eventual drop by 2070 also caused by high water requirements. Most significant soil parameters influencing the suitability model are drainage, texture and waterlogging susceptibility. And overlay of rocky patches is also incorporated in the model.

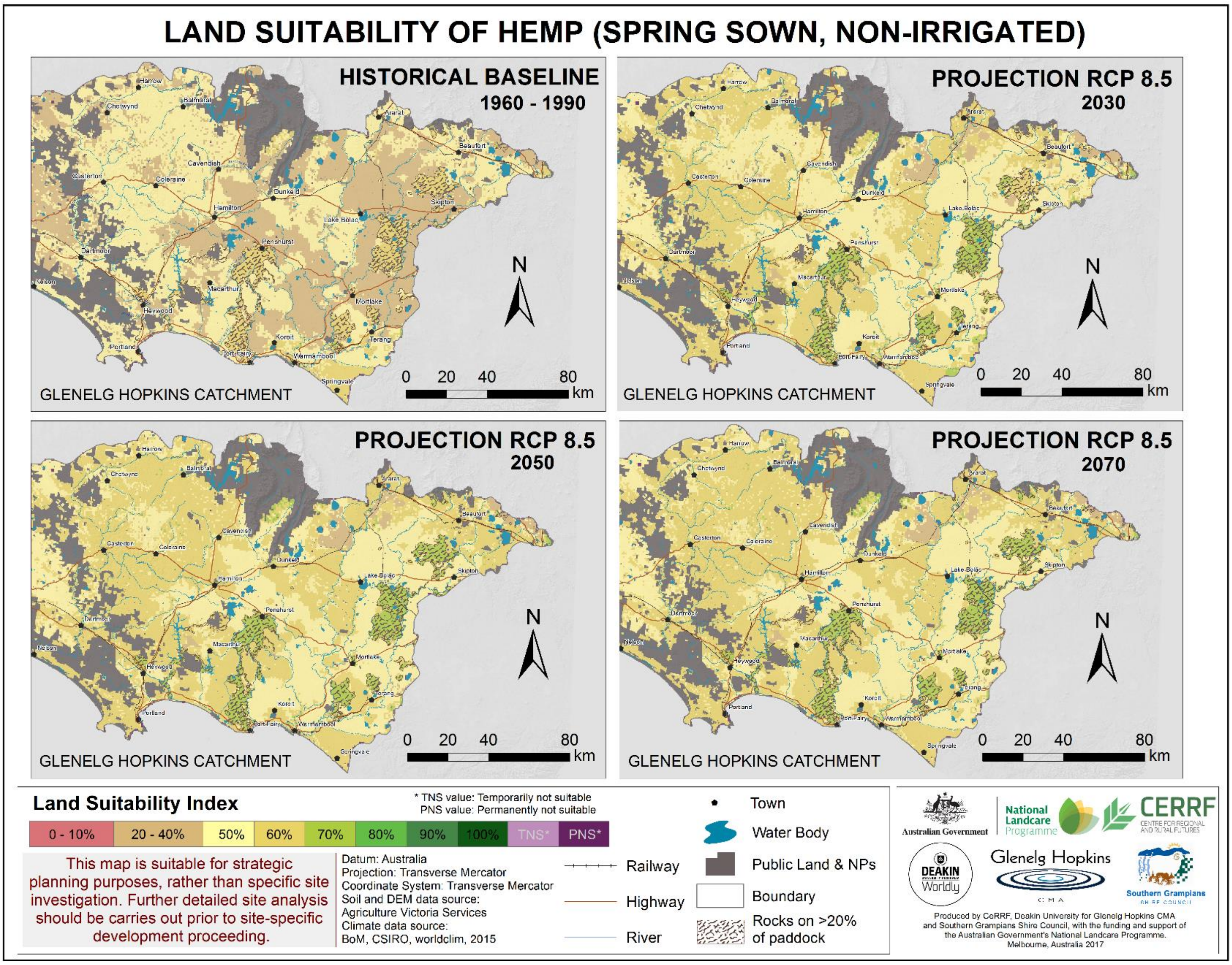

Figure 35 - Spring sown hemp land use suitability maps for baseline of 1960-1990 and climate projections RCP 8.5 for 2030, 2050 and 2070

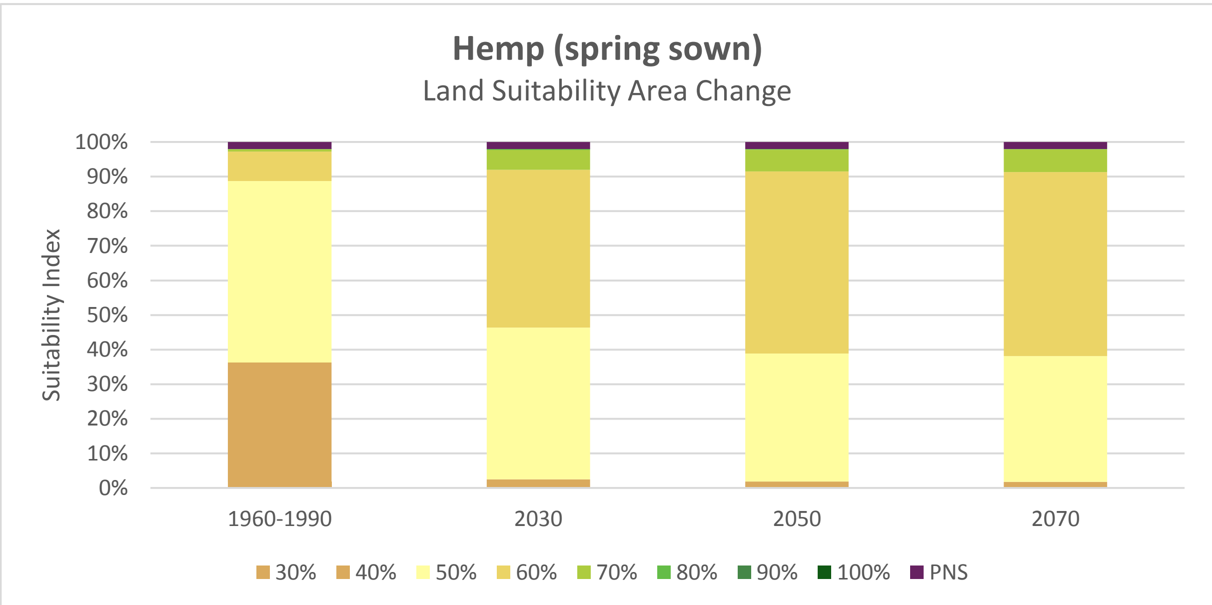

Figure 36 – Spring sown hemp land suitability area change

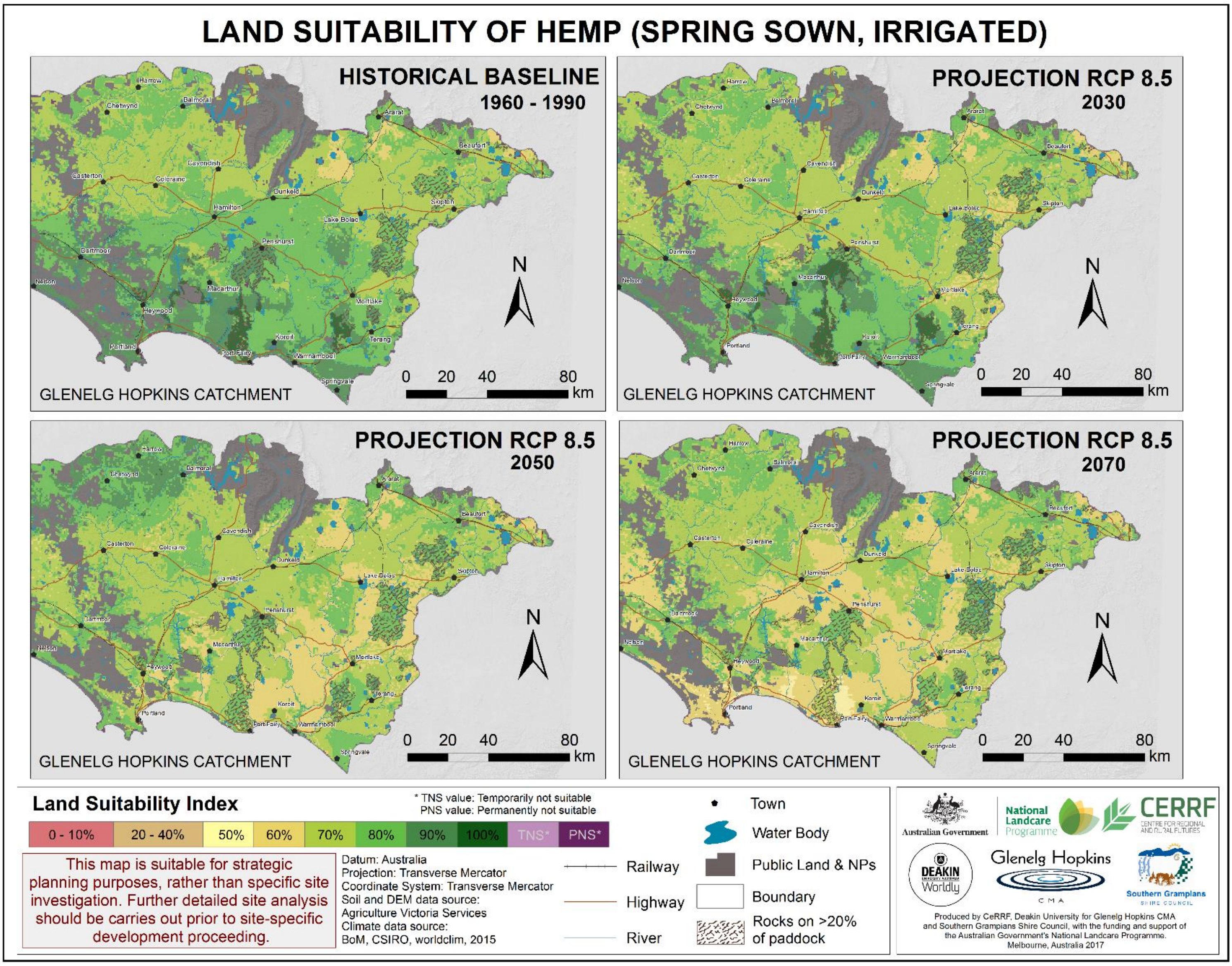

Figure 37 – Irrigated spring sown hemp land use suitability map for baseline of 1960-1990

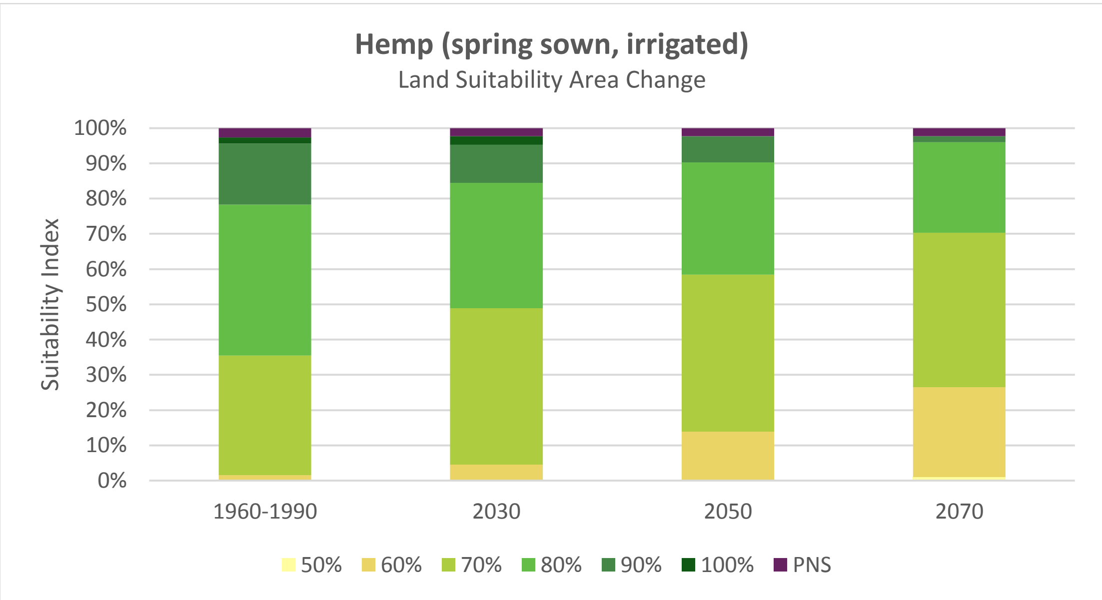

Figure 38 – Irrigated spring sown hemp land suitability area change

13. Concluding remarks

This report has been structured in several components, with a focus on the likely impacts of climate change on the production of barley, red wheat, quinoa, chickpeas, faba beans, mustard seed, sunflower seed and hemp in the Glenelg Hopkins catchment. Figure 39 shows the overall trends in land suitability, indicating that red wheat, barley, mustard seed, faba beans and chickpeas are likely to become more suitable, whereas the suitability of quinoa, hemp and sunflower is projected to decline. The overall trend in land capability of the Glenelg Hopkins catchment is positive, with the overall median suitability index of 69.0% for baseline 1960-1990 projected to increase to approx. 72.9% by 2070 (an average increase in suitability for cropping of 3.9% and median of 9% by 2070). In general, the suitability of winter crops sensitive to waterlogging increases due to projected rainfall decline. Summer crops are likely to benefit from higher temperature, but the increasingly limited water availability often outweighs the impacts of temperature and results in future lower suitability.

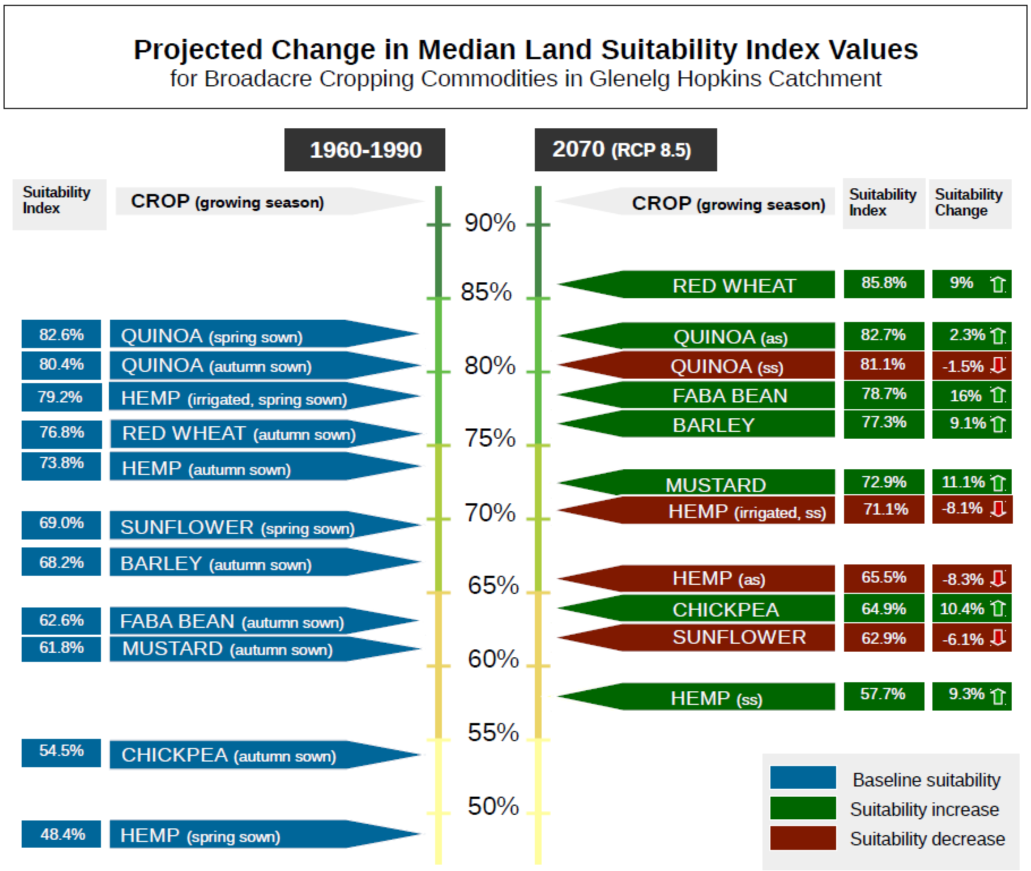

Figure 39 – Projected change in median land suitability index values for broadacre cropping

Within this study, it can be reasoned that for an agriculturally-based region to have the capacity to flexibly respond to changing conditions, it is necessary that significant areas of the available land for agricultural production be able to sustain multiple agricultural uses, either to a particular commodity grouping or for all agricultural systems. Similarly, those areas capable of sustainably producing a variety of commodities (not necessarily at the same time) are considered to be highly versatile. In terms of the suitability modelling, this refers to land which has been categorised as suitable for agricultural purposes, especially in the higher ranks (index in the 80-100% range).

Despite the quality of soil and overall suitability of the southern part of the region, the potential of cropping extending into these areas is limited by both historical land use of the coastal areas for dairy and cattle or sheep grazing, and their rising commodity prices that currently outcompete grain production on Australian as well as world markets, despite growing demand (AgAnswers 2017).

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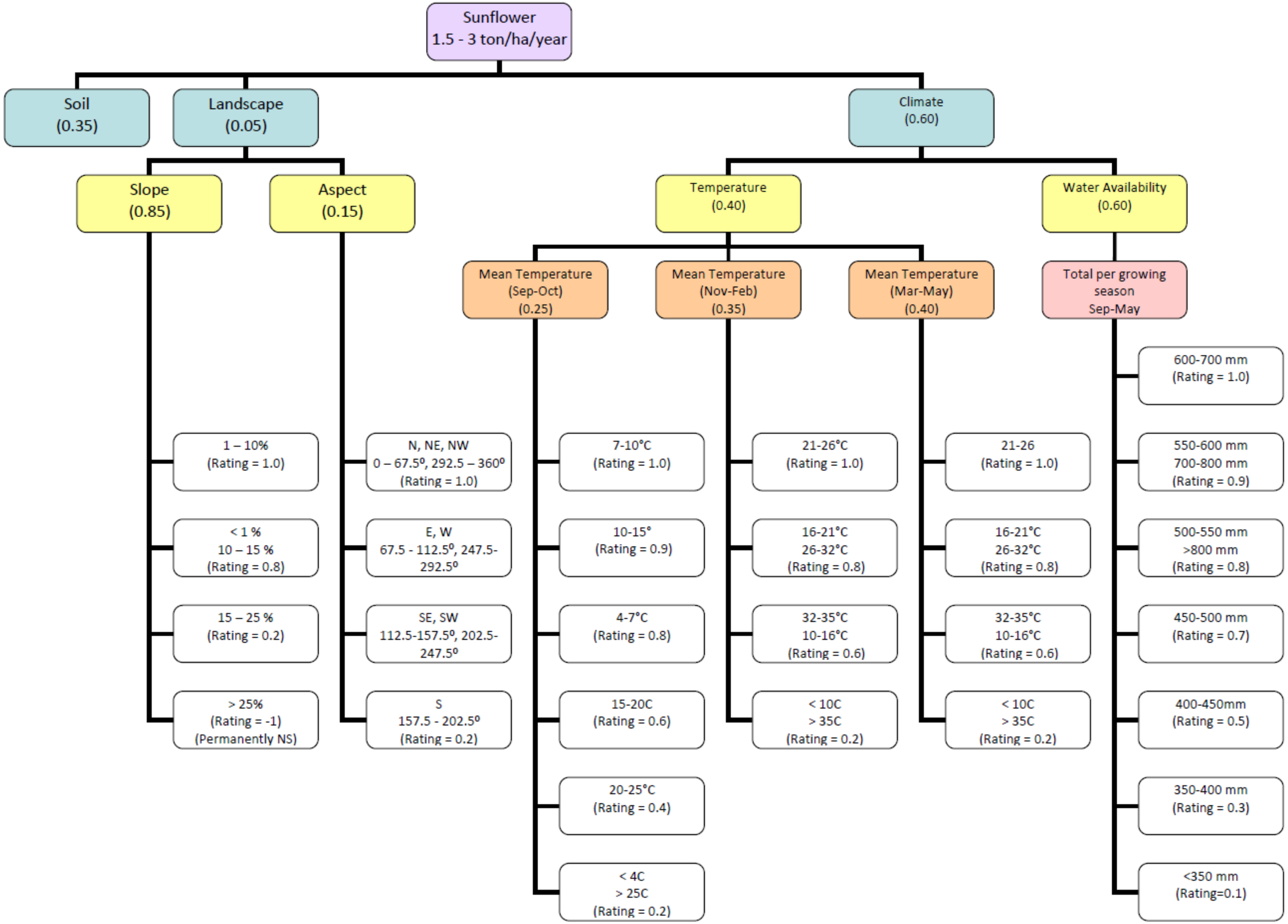
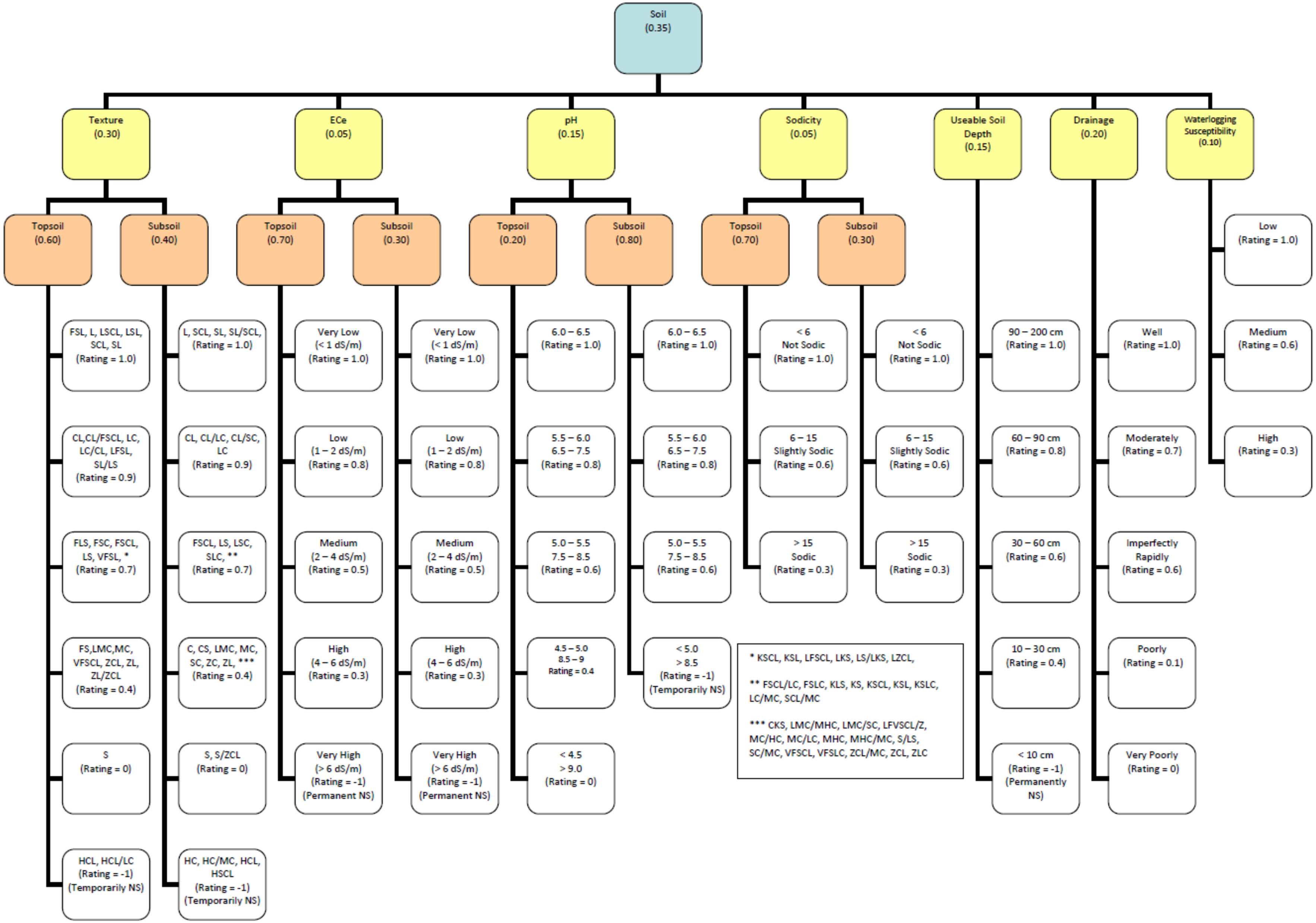
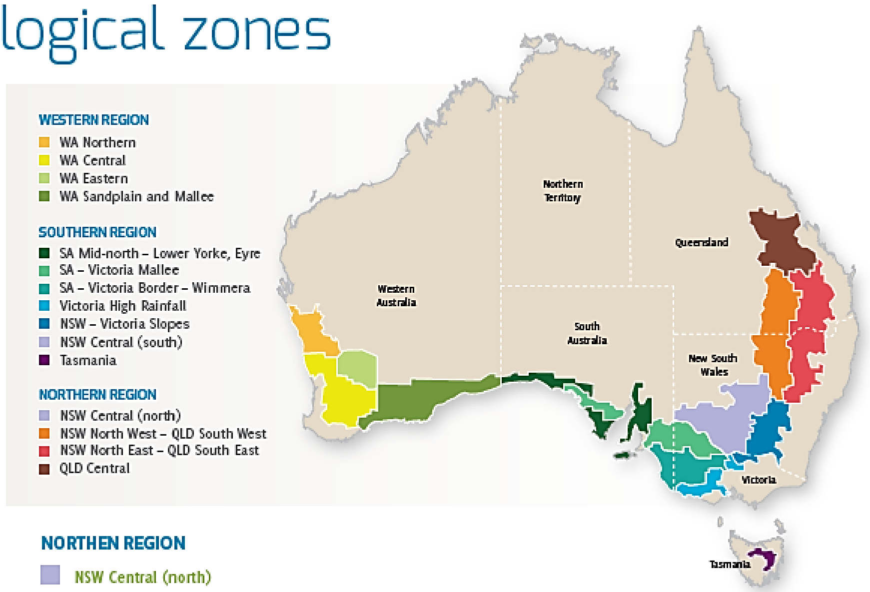
Appendix I – Sunflower (spring sown) hierarchy




Soil (0.35)
Texture (0.30)
ECe (0.05)
pH (0.15)
Sodicity (0.05)
Useable Soil Depth (0.15)
Drainage (0.20)
Waterlogging Susceptibility (0.10)
Topsoil (0.60)
Subsoil (0.40)
Topsoil (0.70)
Subsoil (0.30)
Topsoil (0.20)
Subsoil (0.80)
Topsoil (0.70)
Subsoil (0.30)
FSL, L, LSCL, LSL, SCL, SL (Rating = 1.0)
CL,CL/FSCL, LC, LC/CL, LFSL, SL/LS (Rating = 0.9)
FLS, FSC, FSCL, LS, VFSL, * (Rating = 0.7)
FS,LMC,MC, VFSCL, ZCL, ZL, ZL/ZCL (Rating = 0.4)
S (Rating = 0)
HCL, HCL/LC (Rating = -1) (Temporarily NS)
L, SCL, SL, SL/SCL, (Rating = 1.0)
CL, CL/LC, CL/SC, LC (Rating = 0.9)
FSCL, LS, LSC, SLC, ** (Rating = 0.7)
C, CS, LMC, MC, SC, ZC, ZL, *** (Rating = 0.4)
S, S/ZCL (Rating = 0)
HC, HC/MC, HCL, HSCL (Rating = -1) (Temporarily NS)
Very Low (< 1 dS/m) (Rating = 1.0)
Low (1 – 2 dS/m) (Rating = 0.8)
Medium (2 – 4 dS/m) (Rating = 0.5)
High (4 – 6 dS/m) (Rating = 0.3)
Very High (> 6 dS/m) (Rating = -1) (Permanent NS)
Very Low (< 1 dS/m) (Rating = 1.0)
Low (1 – 2 dS/m) (Rating = 0.8)
Medium (2 – 4 dS/m) (Rating = 0.5)
High (4 – 6 dS/m) (Rating = 0.3)
Very High (> 6 dS/m) (Rating = -1) (Permanent NS)
6.0 – 6.5 (Rating = 1.0)
5.5 – 6.0 6.5 – 7.5 (Rating = 0.8)
5.0 – 5.5 7.5 – 8.5 (Rating = 0.6)
4.5 – 5.0 8.5 – 9 Rating = 0.4
< 4.5 > 9.0 (Rating = 0)
6.0 – 6.5 (Rating = 1.0)
5.5 – 6.0 6.5 – 7.5 (Rating = 0.8)
5.0 – 5.5 7.5 – 8.5 (Rating = 0.6)
< 5.0 > 8.5 (Rating = -1) (Temporarily NS)
< 6 Not Sodic (Rating = 1.0)
6 – 15 Slightly Sodic (Rating = 0.6)
> 15 Sodic (Rating = 0.3)
< 6 Not Sodic (Rating = 1.0)
6 – 15 Slightly Sodic (Rating = 0.6)
> 15 Sodic (Rating = 0.3)
90 – 200 cm (Rating = 1.0)
60 – 90 cm (Rating = 0.8)
30 – 60 cm (Rating = 0.6)
10 – 30 cm (Rating = 0.4)
< 10 cm (Rating = -1) (Permanently NS)
Well (Rating =1.0)
Moderately (Rating = 0.7)
Imperfectly Rapidly (Rating = 0.6)
Poorly (Rating = 0.1)
Very Poorly (Rating = 0)
Low (Rating = 1.0)
Medium (Rating = 0.6)
High (Rating = 0.3)
* KSCL, KSL, LFSCL, LKS, LS/LKS, LZCL,
** FSCL/LC, FSLC, KLS, KS, KSCL, KSL, KSLC, LC/MC, SCL/MC
*** CKS, LMC/MHC, LMC/SC, LFVSCL/Z, MC/HC, MC/LC, MHC, MHC/MC, S/LS, SC/MC, VFSCL, VFSLC, ZCL/MC, ZCL, ZLC

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