LAND CAPABILITY ASSESSMENT

Of Glenelg Hopkins Catchment

Technical Report: **Horticulture**

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

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

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1. Executive Summary

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

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

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

The project has been co-funded by the Glenelg Hopkins CMA with the support of the Australian Government's National Landcare Programme, Southern Grampians Shire Council and Deakin University. This report outlines an analysis of the potential implications of regional climate change on horticulture, through GIS modelling of fruit: citrus, berries, stone fruit (early), stone fruit (late), pome fruit (early), and pome fruit (late). 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.

The projected higher mean temperature is likely to stimulate ripening of fruit, increasing the suitability of horticultural commodities. The accompanying decline in chill accumulation can cause insufficient vernalisation and hinder fruit development. Weather extremes such as frost, heat, hail, wind, and storm activity are likely to negatively impact yields. Irrigation is required for all modelled commodities, with the irrigation requirement increasing out to 2070 due to higher evapotranspiration and lower effective rainfall. The necessity of horticultural commodities to be irrigated negatively impacts on their suitability for the Glenelg Hopkins CMA region due to the currently limited access to water suitable for irrigation, especially in the north-west part of the catchment. Southern part of region and areas around Ballarat and Colac have access to high-yielding ground water aquifers with low salinity levels, making them more likely to be able to support horticultural industry. Compared to broadacre crops and hay from pastures, fruit is highly perishable, and as such requires adequate storage and chilling facilities, careful handling during harvest, storage and transport. The quality of infrastructure and distance to market or processing plants are of paramount importance in terms of product quality, and are likely to be a challenge for horticultural businesses in the region.

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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
LSA	Land Suitability Assessment
MCA	Multi Criteria Analysis
NASA	National Aeronautics and Space Administration
NRM	Natural Resource Management region
PNS	Permanently Not Suitable
RCP	Representative Concentration Pathways
RIRDC	Rural Industries Research & Development Corporation
SILO	Scientific Information for Land Owners
SRTM	Shuttle Radar Topography Mission
TNS	Temporarily Not Suitable
USGS	United States Geological Survey
VIC	The State of Victoria
VLUIS	Victorian Land Use Information System
VRO	Victorian Resources Online
WA	The State of Western Australia
WMO	World Meteorological Organisation
WorldClim	Global Climate Data

4. Key Definitions

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

5. Acknowledgements

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

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

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

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

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

6. Introduction

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

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

7. Project Scope and Strategic Objectives

The land suitability assessment part of this project, as the main subject of this report, aims to determine the extent of climate change impacts on the yield of selected fruit commodities. A list of 6 fruit commodities 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 horticultural industry. 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 horticultural industries 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 fruit 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.

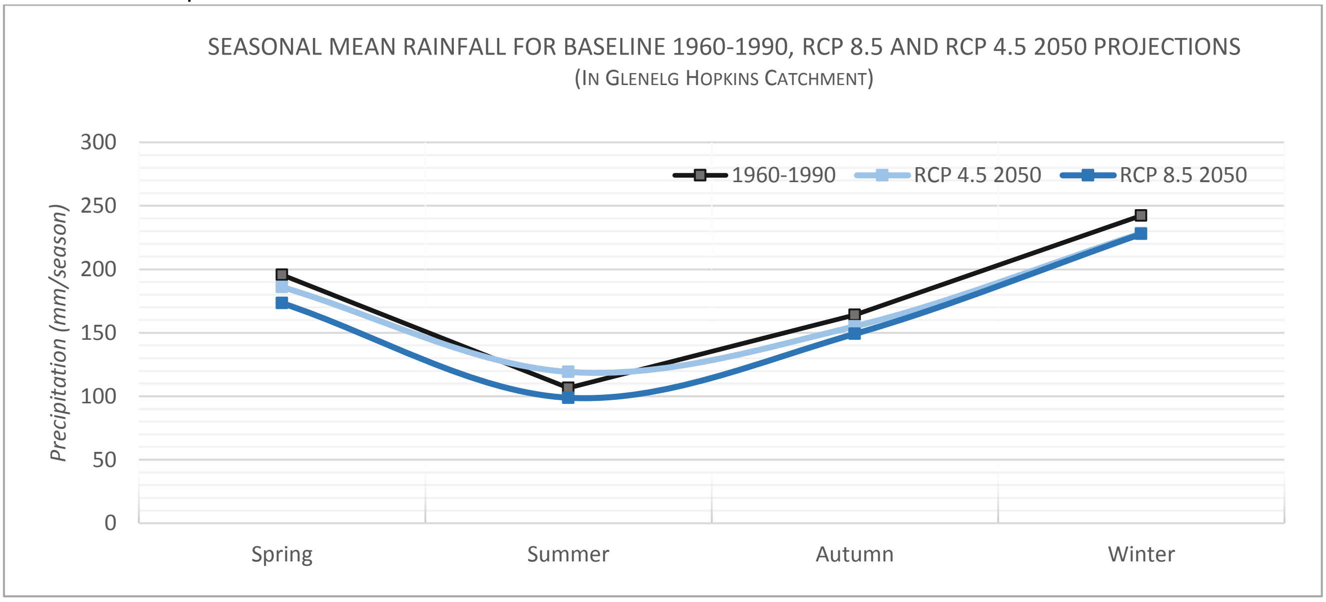

Figure 1 - Seasonal Mean Rainfall for baseline, RCP 4.5 and RCP 8.5 2050

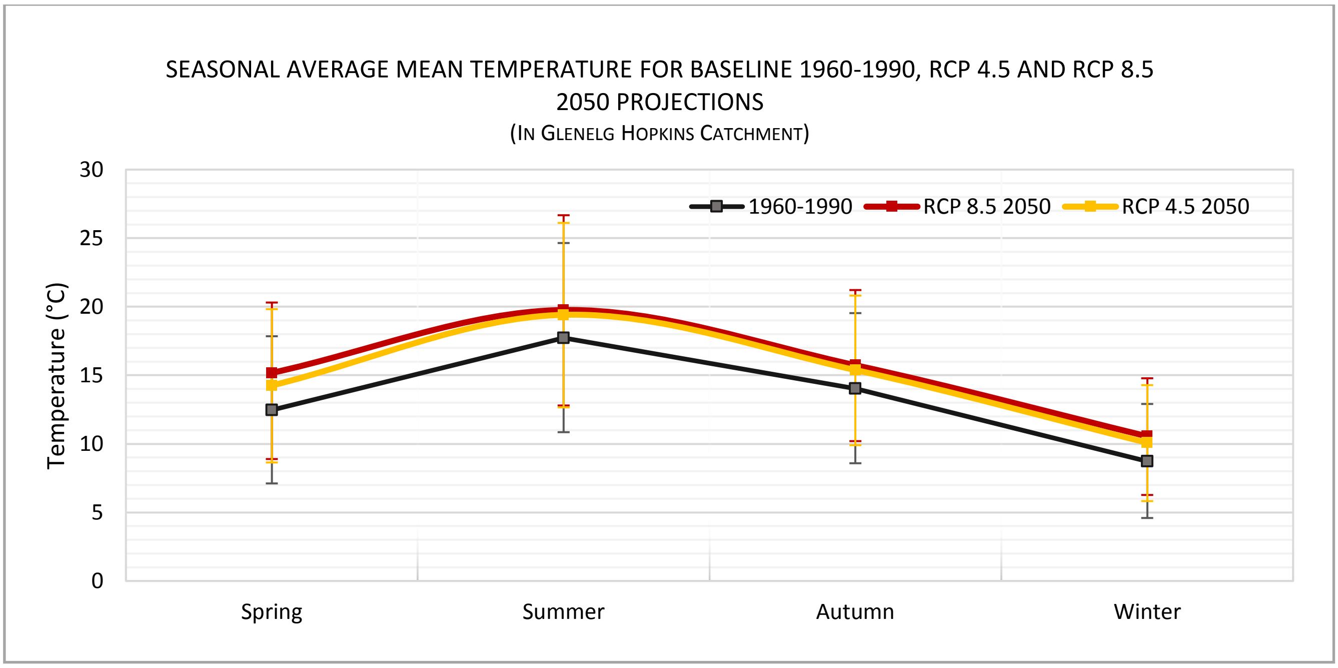

Figure 2 - Seasonal average of mean temperature for baseline, RCP 4.5 and RCP 8.5 2050 (with deviation bars showing average maximum and minimum temperatures for particular season)

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 fruit species 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.

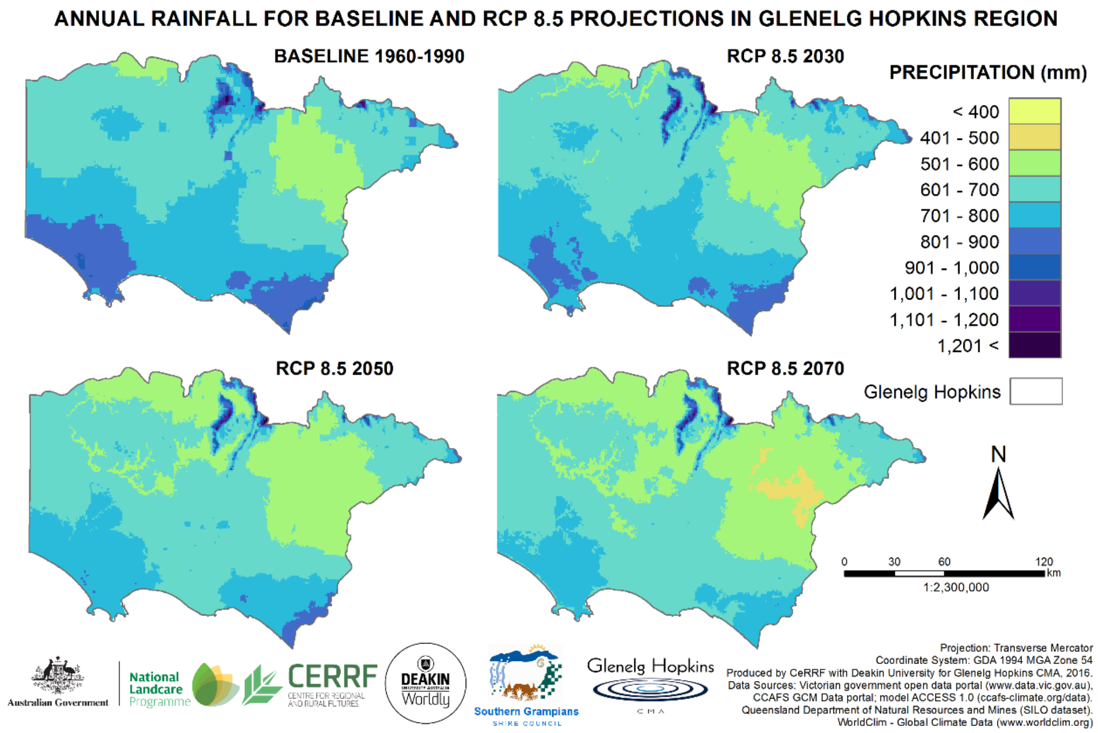

Figure 3 - Mean annual rainfall for baseline 1960-1990 and RCP 8.5 projections

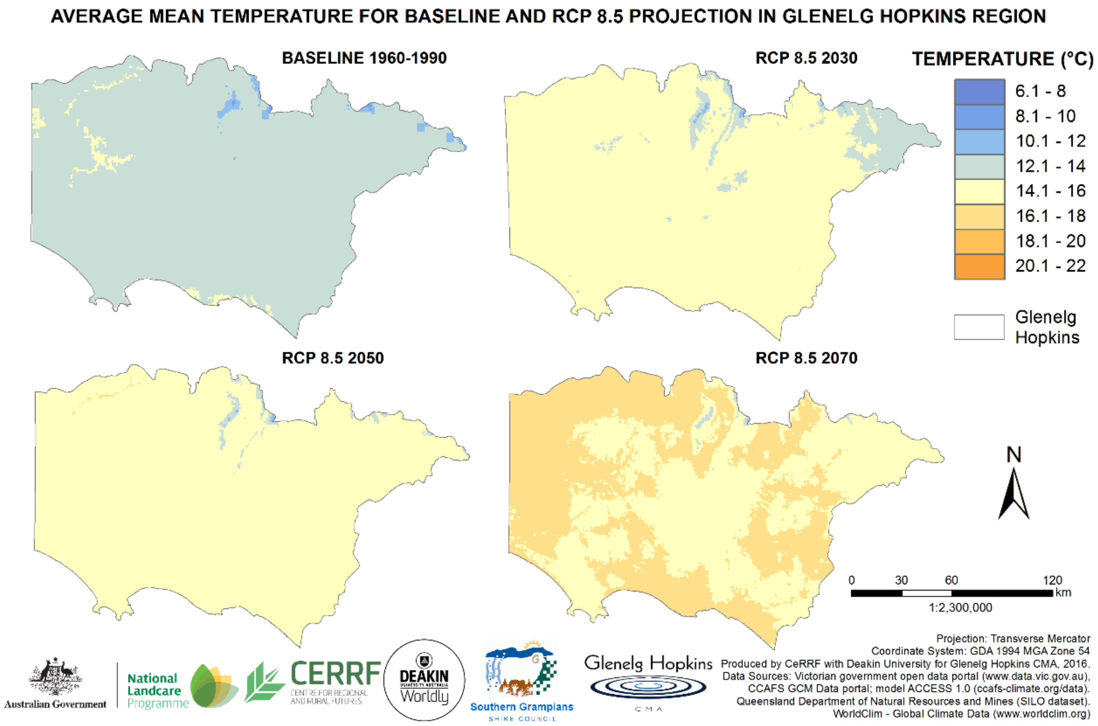

Figure 4 - Annual Mean Temperature for baseline 1960-1990 and RCP 8.5 projections

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 fruit 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.

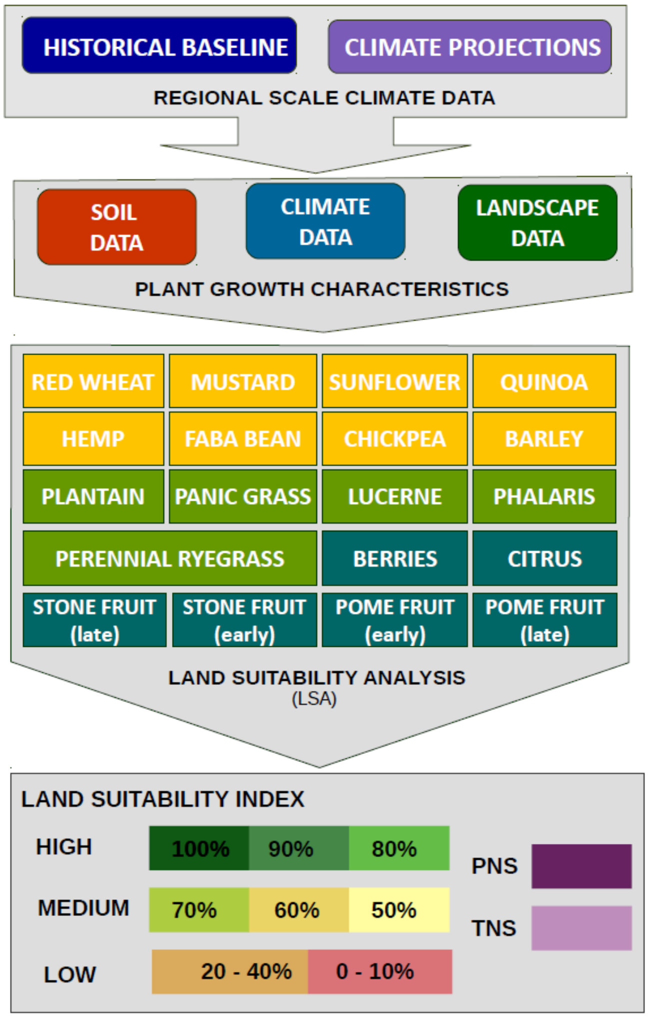

Figure 5 – LSA methodology

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 horticultural 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 horticultural production; for instance, the effect that changing climatic conditions may have on bees and pollination, or on plant disease status. It also does not consider management practices that also significantly influence 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. Irrigation is vital for a successful fruit production in the region. LSA models used in this project base the final water use of commodities on a calculated irrigation requirement and effective rainfall, and operate under the assumption that irrigation water of sufficient quality is available. As presented in Chapter 12.2 on water use, this is currently not the case in some areas of Glenelg Hopkins catchment. *Water availability for irrigation and its quality therefore presents a major consideration when dealing with horticultural commodities* and is a part of a different study.

9. This study contains a number of commodities that are either grown on a small commercial scale limited to a certain area of the catchment or not at all (such as quinoa, hemp, Citrus, panic grass etc.). The lack of growers in the region made it harder to validate such models. They are predominantly reliant on scientific literature and expert opinion of agronomists and farmers growing similar pasture species, and will be amended once more trials are available from the region.

10. 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.

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

10. Biophysical Data Inputs

10.1 Observed Climate

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

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

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

10.2 Future Climate

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

10.3 Landscape

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

10.4 Soils

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

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

Table 1 – Soil attributes included in the LSA models

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

11. Validation

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

Initial AHP land-use suitability models were formulated based on previously-developed LSA models for different regions of Victoria. These were adapted and adjusted for use in the Glenelg Hopkins catchment through a thorough literature review, and run to produce a preliminary output map of suitability. The initial maps, for the baseline climate, were then reviewed by local 'experts' (farmers, farming groups, agronomists, plant breeders, among others) in the most prominent fruit production areas of Glenelg Hopkins region around Portland. 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 low, due to the limited number of fruit producing businesses in Glenelg Hopkins region (statistics ca be found in the next chapter in Figure 7).

For both pome and stone fruit, early varieties are more suitable to the region because local climate conditions with a typical onset of autumn break between April and May hinder ripening of late varieties. For citrus, current horticultural areas around Portland get too wet too early in the growing season to get a successful harvest, and would be therefore more suitable further north. In general, the feedback stressed the need for irrigation and the historical presence of commercial scale fruit production in the south west of the catchment around Portland and Nelson. The importance of adequate chilling was also mentioned as well as the potential negative impacts of extreme weather (excessive frost, heat, wind, hail etc.). Insufficient infrastructure in the region (both road/rail and irrigation) and high initial costs of farm-level investment and set-up were also pointed out during the validation.

12. Horticultural Production

12.1 Fruit Production in Victoria and Glenelg Hopkins

In terms of gross value (AU$) of Australian production, the state of Victoria has produced the highest amount of fruit and nut commodities, accounting for approximately 30% of the production in 2015-2016 (ABS 2016). As presented in Figure 6, the highest yielding Natural Resource Management (NRM) regions of Victoria are Mallee and Goulburn Broken accounting for over 80% of the overall fruit and nut production. The bottom five producing NRMs account for less than 1% of the production, Glenelg Hopkins having the lowest value of fruit and nut production of 0.05% (ABS 2016).

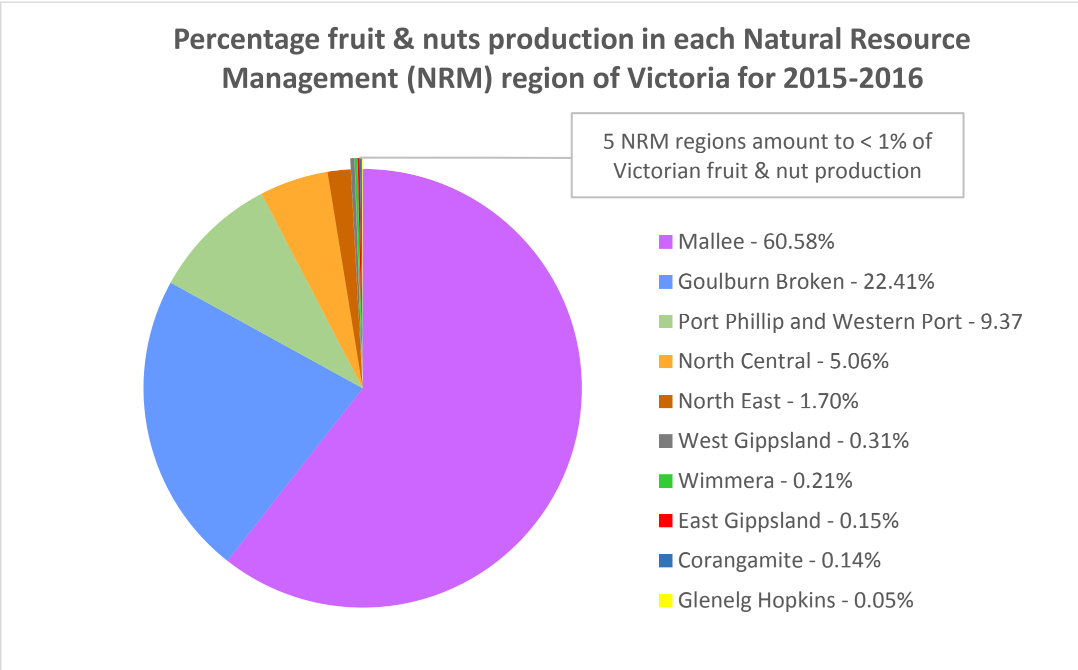

Figure 6 – Percentage fruit & nuts production in each NRM region of Victoria for 2015-2016 source: ABS, 2016

Figure 7 then shows the gross value of specific groups of fruit and nut production in Glenelg Hopkins NRM, showing that the only significant fruit commodities commercially grown in the region in 2015-2016 are pome fruit, strawberries and grapes.

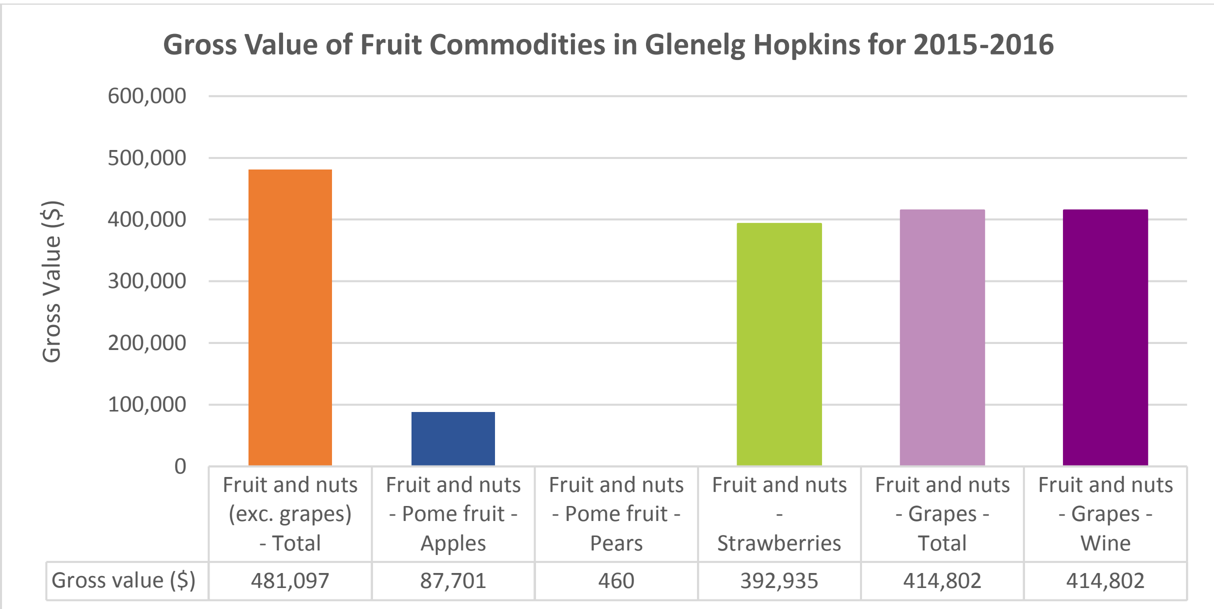

Figure 7 – Gross value (AU$) of fruit commodity groups in Glenelg Hopkins for 2015-2016; source: ABS, 2016

12.2 Regional Climate and Water Use

Chilling

Deciduous fruit trees, including stone trees, develop their vegetative and fruiting buds in the summer. As winter approaches, the already developed buds go dormant in response to both shorter day lengths and cooler temperatures. This dormancy, or sleeping stage, protects buds from the effects of cold weather. Once buds have commenced their dormancy, they will be tolerant to temperatures much below freezing and will not grow in response to mid-winter warm spells.

The buds remain dormant until they have accumulated sufficient chilling, or vernalisation, to break the dormancy. When enough chilling accumulates, the buds are ready to grow in response to warm temperatures. As long as there has been enough accumulated chilling, the flower and leaf buds will develop normally. Maximum chilling tends to occur between 6-8°C, with very little chilling accumulated below 2°C or above 10-12°C (Hennessy and Clayton-Greene 1995). If the buds do not accumulate sufficient chilling during winter to completely release dormancy, trees can develop delayed foliation, reduced fruit set and buttons or reduced fruit quality. Different cultivars require different chilling requirements as their flowering and growing periods occur at different times from one another. Extended periods of frost, on the other hand, can severely damage the crop, especially during flowering. Same negative impacts are caused by other extreme weather events, such as excessive heat, hail, winds and storm activity in general, whose incidence is projected to increase in the future (STOKES & HOWDEN 2010). If the buds do not accumulate sufficient chilling during winter to completely release dormancy, trees will develop one or more of the physiological symptoms associated with insufficient chilling. These include the following.

- **Delayed foliation** – A tree may have a small tuft of leaves near the tips and be devoid of leaves for 30-50 centimetres below the tips. Lower buds would eventually break, but full foliation is significantly delayed, fruit set is reduced, and the tree is weakened.
- **Reduced fruit set and buttons** – Flowering, in response to insufficient chilling, often follows the pattern seen with leaf development. Bloom is delayed, extended, and due to abnormalities in pistil and pollen development, fruit set is reduced. In some cases, buttons result from flowers that apparently have set but never develop into full-size fruit.
- **Reduced fruit quality** – These effects are subtle and can occur when other symptoms do not. In the instance of pome fruit, insufficient chilling will cause many cultivars to have an enlarged tip and reduced firmness. The fruit background coloration may be greener than usual, possibly due to the fruit loosing firmness before the background colour can fully change from green to yellow.

Irrigation

Glenelg Hopkins catchment has a number of aquifers at different levels, whose water quality differs significantly, especially in terms of salinity. All levels of ground water are shown in Figure 8, Figure 9 and Figure 10. Middle aquifers are predominantly used by agribusinesses, since they generally provide higher yields and better quality water than upper aquifers (Southern Rural Water 2011), but they are predominantly situated in the southern half of the region. The quality of water used in horticulture is essential, influencing plant growth, yields but also taste and fruit quality (Department of Agriculture and Food 2016; Shannon & Grieve 1998; Mizrahi & Pasternak 1985) As demonstrated in Figure 9, the salinity levels in majority of the catchment's middle aquifers are less than 3500mg/L. Even though the upper aquifers underlie majority of the region, their quality is lower than that of middle and lower ones, with the exception of aquifers close to the border with South Australia, near Ballarat and Colac that provide high yielding and good quality groundwater (Southern Rural Water 2011).

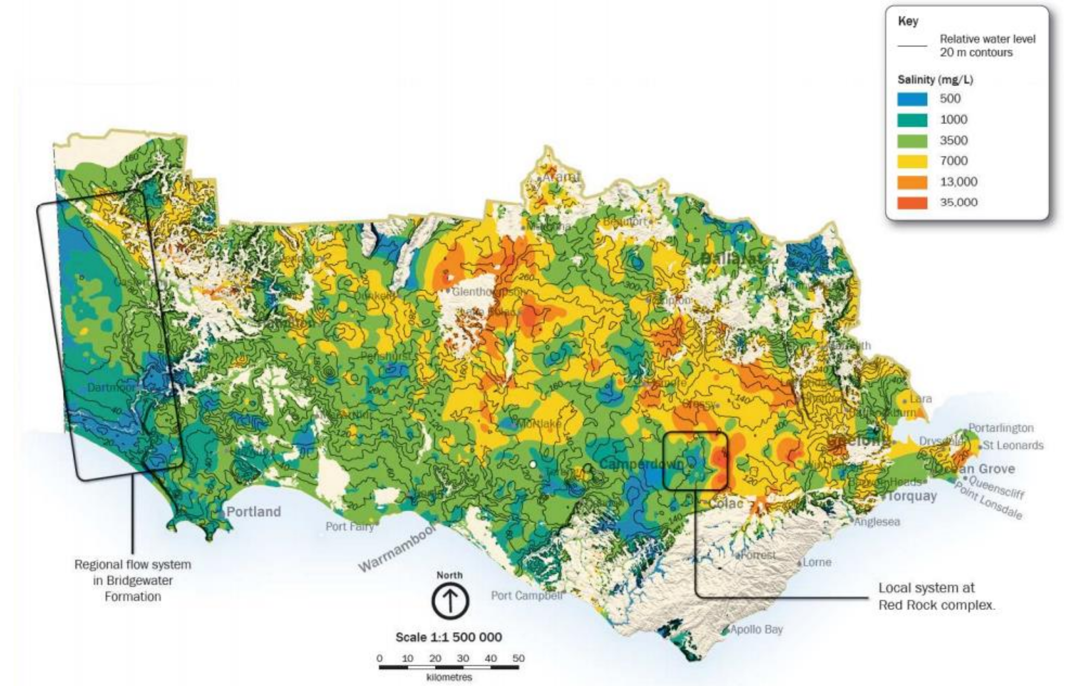

Figure 8 – Map of salinity of ground water in the Upper aquifers in South West Victoria (source: Southern Rural Water 2011)

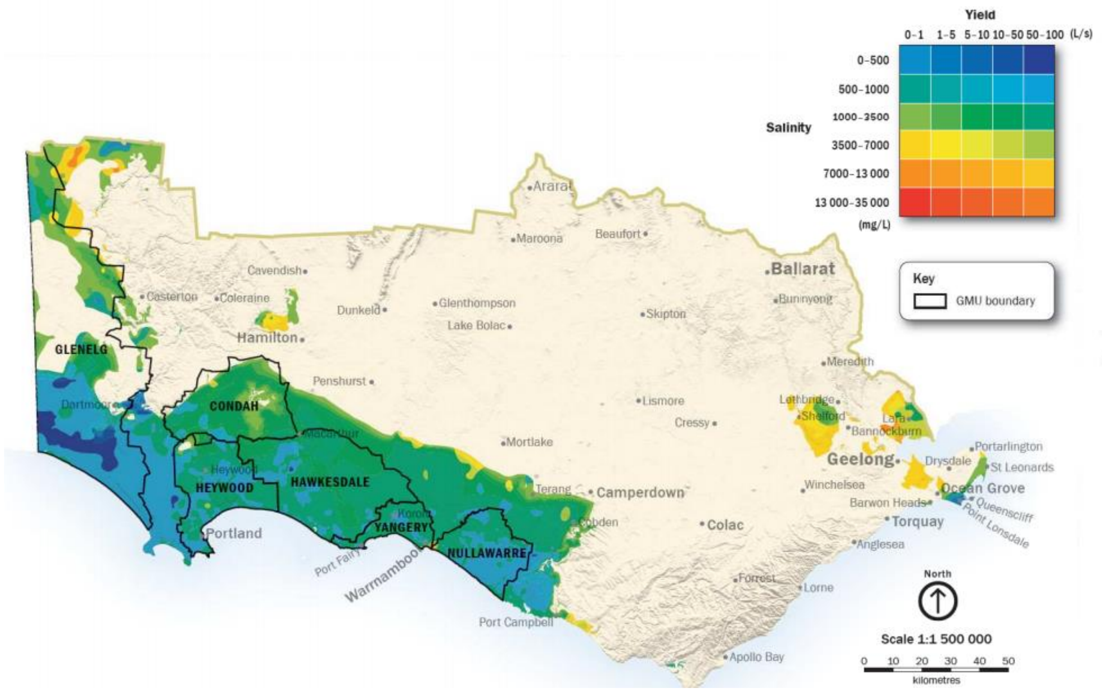

Figure 9 - Map of salinity and yield of ground water in the Middle aquifers in South West Victoria (source: Southern Rural Water 2011)

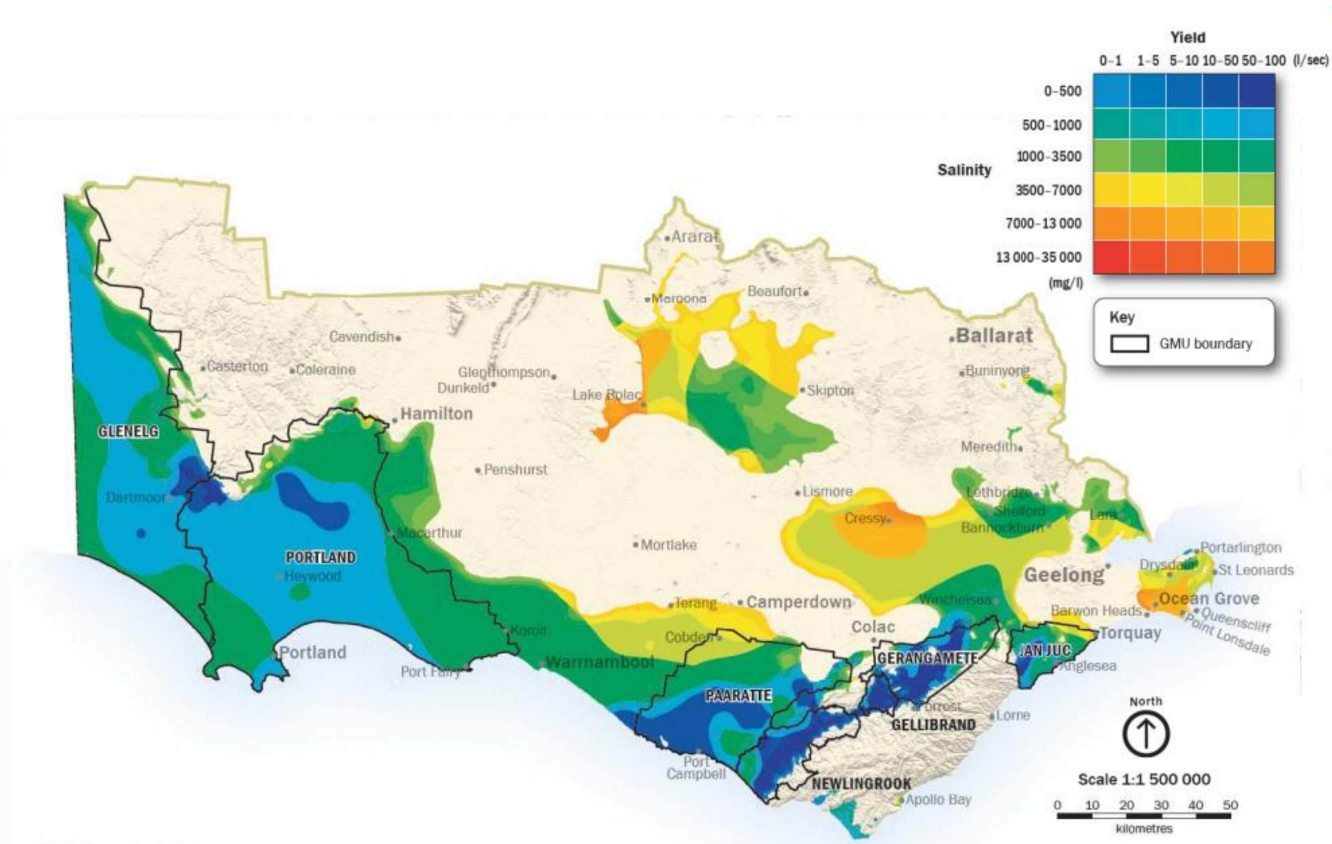

Figure 10 - Map of salinity and yield of ground water in the Lower aquifers in South West Victoria (source: Southern Rural Water 2011)

Water use was determined for each commodity, using effective rainfall, irrigation requirement, evapotranspiration, and soil water reserve, as specified below. Irrigation need has been calculated for every month of a growing cycle specific to each commodity, based on a crop coefficient changing between the initial, mid-season and end of late season stages (Allen et al. 1998). 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.

Irrigation requirement values and their projected change with shifts in climate are presented at separate sections of this report, specific to each commodity. Figure 11 shows the projected change in seasonal evapotranspiration based on the mean of all evapotranspiration values in the catchment. Consistent with the likely increase in mean temperature, evapotranspiration is projected to increase by 118 mm/day or 9.6% between 1960-1990 and 2070.

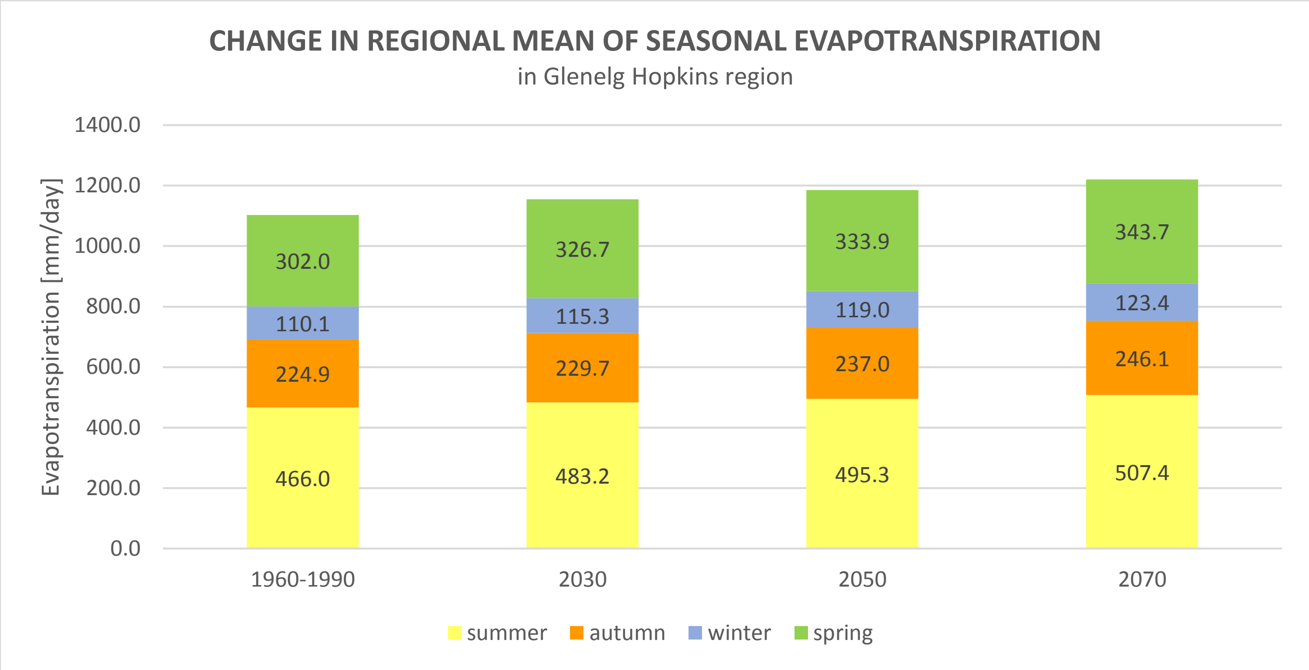

Figure 11 – Change in regional mean of seasonal evapotranspiration

Figure 12 shows the projected change in seasonal effective rainfall based on the mean of all aggregate rainfall values in the catchment. Due to high precipitation variability across the region (much higher than the temperature variability), the data is presented to demonstrate general trends rather than specific values. Projected values indicate a decrease in spring, autumn rainfall and winter effective rainfall, and an increase in summer rainfall. An overall drop in effective rainfall levels of 77.8 mm/year or 25% is projected. The likely increase in evapotranspiration and decrease in effective rainfall both indicate higher irrigation requirements in the future.

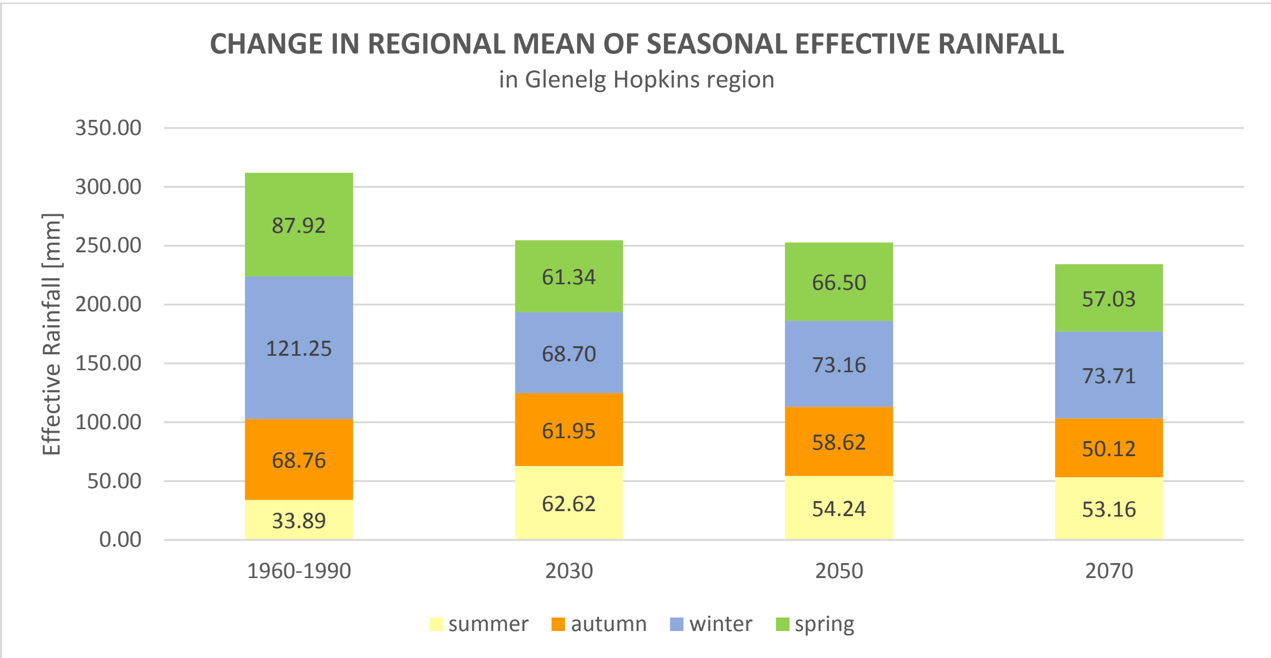

Figure 12 – Change in regional mean of seasonal effective rainfall

A. Stone Fruit

Stone fruit trees are deciduous and grow to a height of 5 to 10 metres. They can live from 20 to 30 years in age, but in cultivated commercial plantings the life span is from 12 to 15 years, mainly due to loss in fruiting productivity (Bassi & Monet, 2008). Stone fruit trees produce flowers, which differ in appearance according to cultivar however are usually small and white or pink in colour.

Stone fruit trees produce a wide range of fruits from a variety of cultivars. Peaches, nectarines, plum and apricots are round in shape and skin colours range from red, yellow to white. Flesh colours also vary both between cultivars and across varieties. Fruits mature at different times and undergo differing and complex flowering, maturing and harvesting seasons, shown in Appendix II. Any businesses growing stone fruit on a commercial scale have not been identified and are not included in the ABS agricultural statistics of Glenelg Hopkins region for 2015-2016.

Stone fruit trees can be highly adaptable to a range of different soils, although they do prefer soils with high sand to clay ratio or loamy type soils (Bellini *et. al.,* 2009). The root system is ideally developed in deeper soil profiles of more than 1m. The trees prefer well drained soils and do not tolerate waterlogging. The optimal pH_{Ca} range is near neutral from 6.5 to 7.5. At the higher and lower levels of the pH_{Ca} range, soil conditions will become unsuitable for production. Higher pH levels, for example, can induce *foliar chlorosis*, a condition where the leaves don't produce enough chlorophyll. Salinity levels below 2 dS/m are preferred; levels above 3 dS/m can impair peach and nectarine growth (Bellini *et. al.,* 2009), as indicated in the above section on water use and irrigation.

Landscape characteristics for a stone fruit orchard contribute to the growth and development of fruit more significantly than in previous commodity groups of cropping and pastures. Trees prefer full sunlight, although areas with minimal shading are tolerated. A north west to north east aspect is optimal as these will receive greater amounts of sunlight during spring days. A southerly aspect receives less sunlight; hence it can be colder and be more susceptible to frosts, negatively impacting fruit trees in flowering stage. A slight and gentle slope is optimal for stone fruit trees as this can aid in air drainage. This is particularly important in areas with incidences of spring frosts, a slope will allow cold air to drain away from the orchard into lower areas preventing any frost damage. Low lying areas, for this reason, should be avoided, as these regions can trap colder air which can increase incidences of frost occurring. Steep slopes should be avoided to reduce the risk of soil erosion and nutrient runoff.

Stone fruit are considered less cold hardy than many other tree fruit species. They prefer a temperate climate with cold winters, moderate springs and hot and dry summers. The trees can tolerate very low temperatures during winter, but prolonged period of extremes are likely to damage dormant flower buds. Flowers that develop during spring are extremely sensitive to cold temperatures and frosts; if temperatures fall below -4°C the majority of open flowers can be killed. The fruits, during summer, require high mean air temperatures of up to 30°C. This allows the fruit to mature and ripen sufficiently. Stone fruit do not require cool nights to develop their red skin colour, as seen in apples; the skin colouration is more attributed to the cultivar and light exposure rather than temperatures.

Stone Fruit (early)

Diagrams specifying the timing of maturing for different stone fruit varieties can be found in Appendix II, early maturing examples are: apricots – *Early Divinity or Fireball;* plums – *Santa or Queen Rosa;* nectarines – *Cardinal or Firebrite* and peaches – *Sunset peach or Springcrest*.

Figure 13 shows the change of seasonal irrigation requirement based on a mean of all regional values. Due to the aforementioned likely increase in evapotranspiration and decrease in effective rainfall, stone fruit is projected to need more irrigation to support its production. The warmer stages of the growing season (late spring-summer) require the highest amount of irrigation (increasing the most between the baseline and 2070). The mean irrigation requirement of early stone fruit is projected to change by 19.7% (approximately 140 mm) between the baseline and 2070.

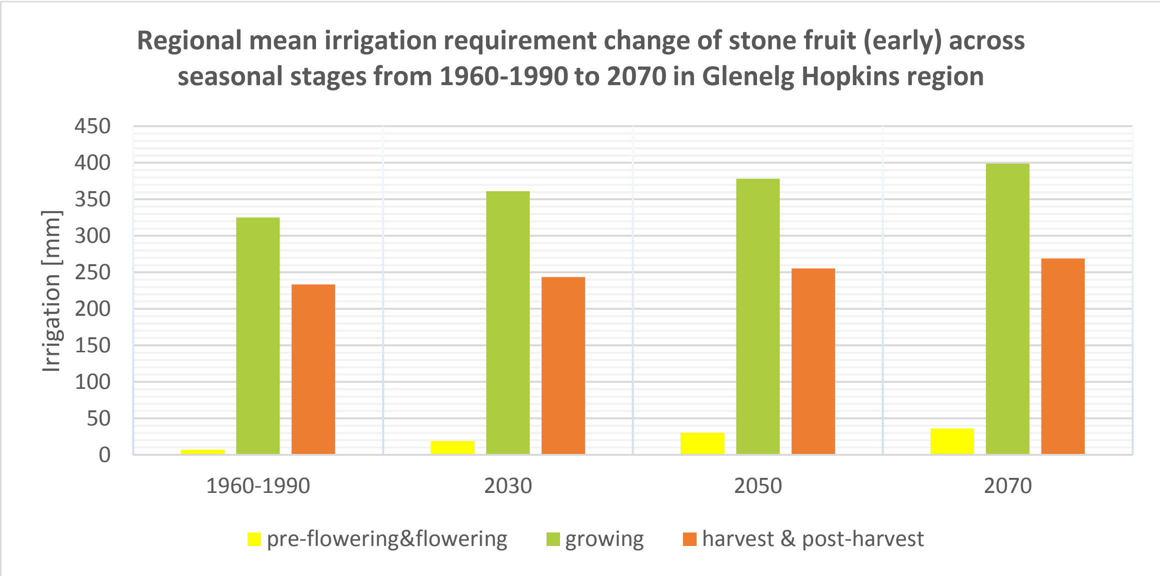

Figure 13 – Regional change in Irrigation requirement for stone fruit (early varieties) between baseline, 2030, 2050 and 2070

Figure 14 presents land suitability maps for early varieties of stone fruit accompanied by a suitability change diagram in Figure 15. Overall climate suitability is projected to significantly decrease in the south while slightly improving in the north of the catchment. Increase in mean temperature, especially during summer and autumn, are counteracted by a decline in the number of chill units, especially in the south, causing the apparent decrease in suitability. Water requirements increase in the future, especially in the north, driving suitability down, but the projected improvement of temperature keeps the suitability in the north at 70-80% even in 2070. The overall suitability of early varieties of stone fruit is projected to increase slightly, by 0.6% between 1960-1990 and 2070. As mentioned in previous sections, even though the projected increase in extreme weather events is likely to have a negative impact on stone fruit production, it could not be accounted for in this study due to the unpredictability of their incidence as well as the nature of the LSA model.

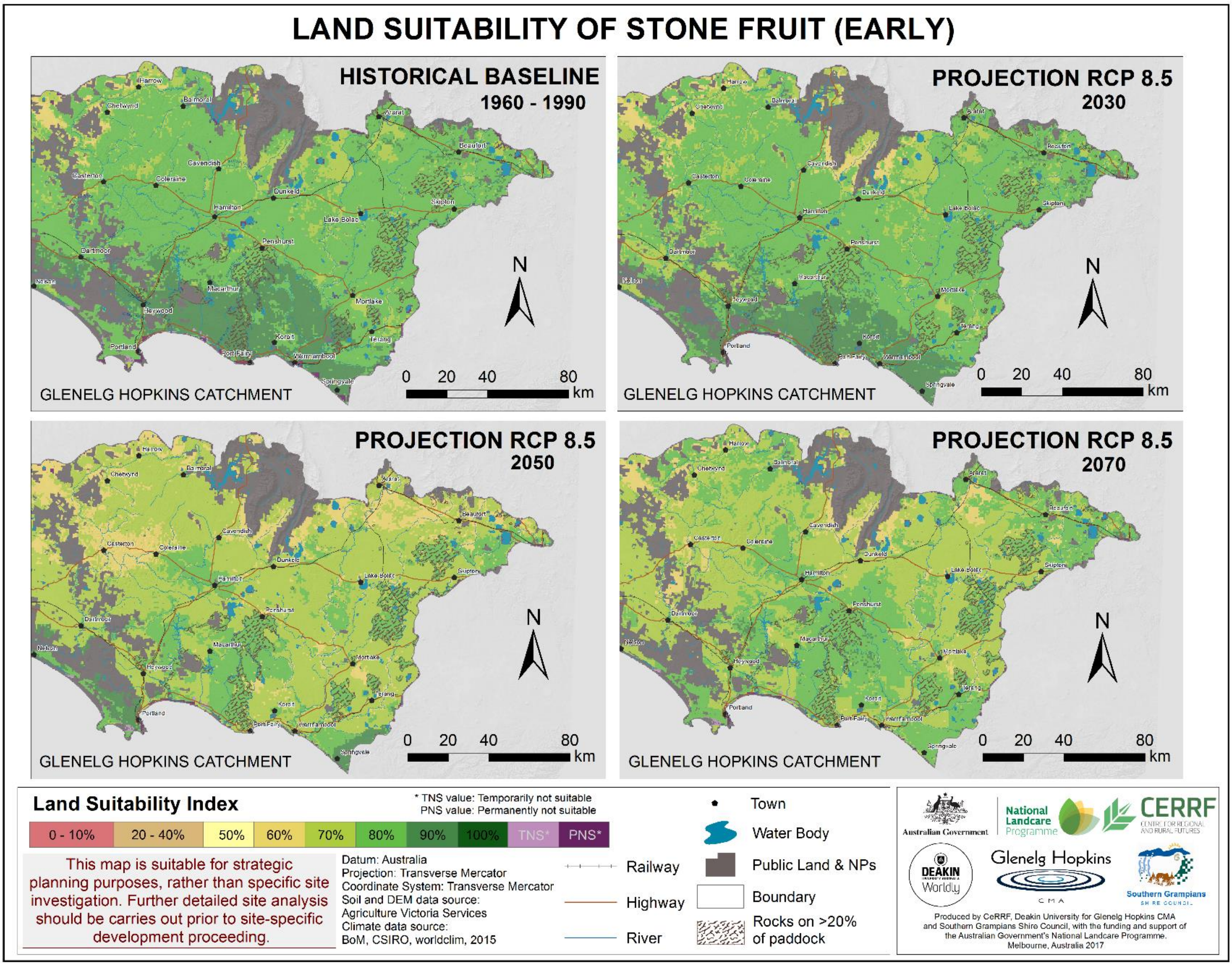

Figure 14 – Land suitability maps of early varieties of stone fruit in Glenelg Hopkins region

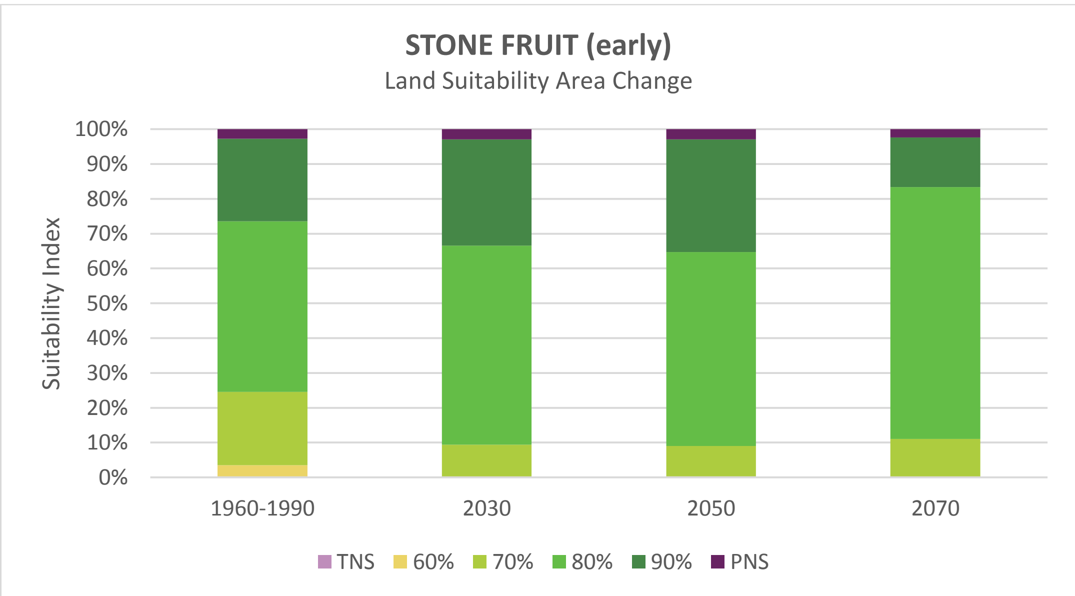

Figure 15 – Land suitability area change of early varieties of stone fruit

Stone Fruit (late)

Diagrams specifying the timing of maturing for different stone fruit varieties can be found in Appendix II, mid and late maturing examples are: apricots – *Hunter*; plums – *Stirling or Ruby Blood*; nectarines – *Fantasia or New Boy*; and peaches – *Elberta or Golden Queen*.

Figure 16 shows the change of seasonal irrigation requirement based on a mean of all regional values. Due to the aforementioned likely increase in evapotranspiration and decrease in effective rainfall, stone fruit is projected to need more irrigation to support its production. The warmer stages of the growing season (summer-early autumn) require the highest amount of irrigation (increasing the most between the baseline and 2070). The mean irrigation requirement of late stone fruit is projected to change by 19.6% (approximately 135mm) between the baseline and 2070.

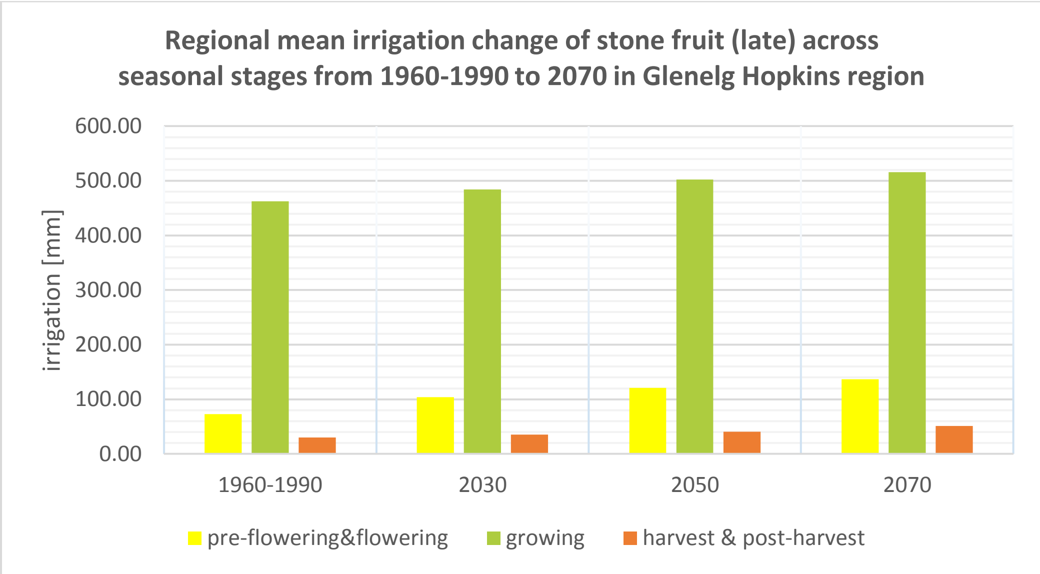

Figure 16 - Regional change in Irrigation requirement for stone fruit (late varieties) between baseline, 2030, 2050 and 2070

Figure 17 presents land suitability maps for late varieties of stone fruit accompanied by a suitability change diagram in Figure 18. Suitability in terms of water requirements is projected to decline, particularly in the north of the catchment due to the projected decline in effective rainfall and increase in evapotranspiration during the delayed growing season (over the hot summer months) when compared to early varieties. Decrease in chill units is also likely to lower the suitability of late stone fruit varieties, predominantly in the south and south-west of the region. The increase in mean temperature counteracts this trend by increasing suitability out to 2070, particularly in the north. The severe increase water use and hence irrigation requirement causes the overall land suitability for late varieties of stone fruit to decline by 6.6% between the baseline and 2070. As mentioned in previous sections, even though the projected increase in extreme weather events is likely to have a negative impact on stone fruit production, it could not be accounted for in this study due to the unpredictability of their incidence as well as the nature of the LSA model.

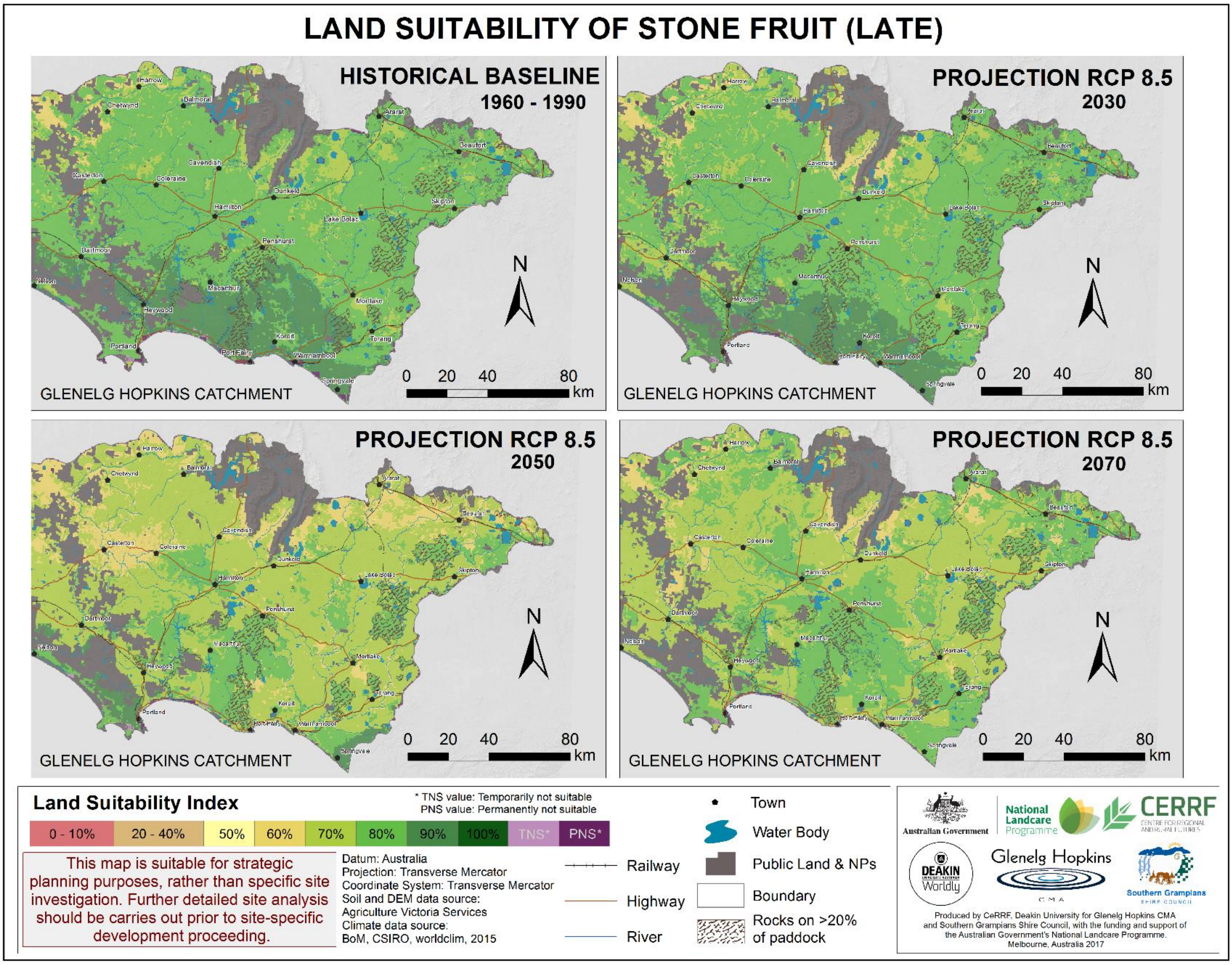

Figure 17 – Land suitability maps of late varieties of stone fruit in Glenelg Hopkins region

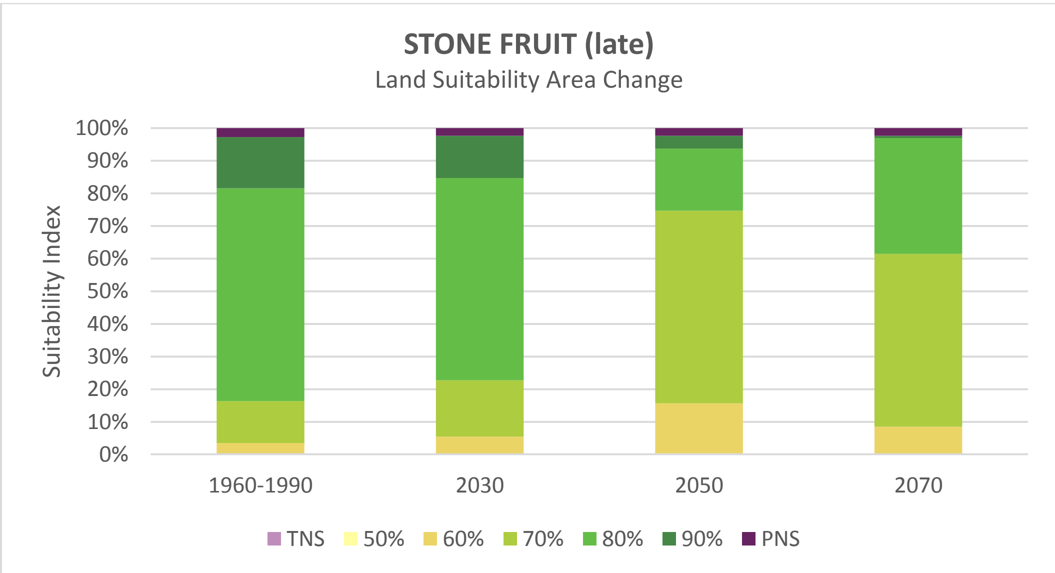

Figure 18 – Land suitability area change of late varieties of stone fruit

B. Pome Fruit

There are many different varieties of apples and pears that are cultivated in Australia. Each of the varieties has their own particular phenological stages; in general, however, all pome fruit will flower from early October to early November and are harvested from February to early May, differentiating between early and late varieties. Varieties that flower early generally tend to have an extended growing phase and are harvested later in the season, whilst the late flowerers have a quick growing phase and are some of the first to be harvested. This occurrence is a reflection of the particular climatic conditions that each variety prefers. Usually, an early flowering varieties are grown in warmer climates, whereas short season cultivars are grown in cooler climates with less frost risk due to late flowering.

While **apple** trees, like most other pome fruits, are tolerant of a range of soils, poor soils do not allow for the production of heavy crops without the application of additional nutrients, making fertile soils more suitable. Apples prefer soils that are well drained but with a good capacity to hold moisture. Typically, they grow best on soils with a clay-loam, silty clay-loam, or other loam texture soils. These types of textured soils have a good water and nutrient holding capacity, but have enough drainage to minimise any moisture retention problems that may affect the apple tree. Deep soils are preferred for apple growth, to allow for greater root penetration and greater chance of both withstanding dry periods and ensuring against root rots during excessively wet periods (Dart, 2008). Optimum pH for apple growth is between 5.5 and 7, however, apples can be tolerant of slightly acidic soils.

Pears have a deep and extensive root system and have traditionally been grown on heavy soils. They can withstand a wet and waterlogged soil better than most other fruit trees and tend to be a long-lived tree. They do not tolerate saline soils; the variety Williams, in particular, is very sensitive to salt damage which causes a brown marginal left scorch and restricts growth. Depending on the ambient pH levels, pear trees are also susceptible to a number of diseases caused by deficiencies in trace elements such as iron, boron or manganese.

Like the majority of pome fruits, **apples** prefer a temperate climate with a cool to cold winter during the maturation period and a mild to warm spring and summer during the growing period. Apple trees need consistently available moisture during their growing season to deliver regular and heavy production. Frosts are harmful once buds begin to open. Strong winds and hail can also create several problems with fruit damage, pollination issues and loss of flower and/or fruit. Windbreaks or sheltered orchards are hence utilised to minimise damage. **Pears** grow well in a temperate climate and in warm inland areas, varieties such as Williams and Winter Nelis are recommended, while areas with mild winters and low chill are more suited to Corella.

Gentle slopes facing north are desirable for the growth of pome fruit trees. Slopes with a south facing aspect are generally colder and hence more prone to frost; they may also not be warm enough in spring to allow for bees to actively pollinate the flowers. Slopes with a north aspect are ideal as they capture more light and hence are warmer. A slight and gentle slope is optimal for pome fruit trees as this can aid in air drainage. This is particularly important in areas with incidences of spring frosts, a slope will allow cold air to drain away from the orchard into lower areas preventing any frost damage. Low lying areas, for this reason, should be avoided, as these regions can trap colder air which can increase incidences of frost occurring. Steep slopes should be avoided to reduce the risk of soil erosion and nutrient runoff.

Pome Fruit (early)

Diagrams specifying the timing of maturing for different pome fruit varieties can be found in Appendix II, early maturing examples are: apples – *Gravenstein, Gala*; pears – *Hood, Corella*.

Figure 19 shows the change of seasonal irrigation requirement based on a mean of all regional values. Due to the aforementioned likely increase in evapotranspiration and decrease in effective rainfall, pome fruit is projected to need more irrigation to support its production. The warmer stages of the growing season (late spring-summer) require the highest amount of irrigation (increasing the most between the baseline and 2070). The mean irrigation requirement of early pome fruit is projected to change by 16.2% (approximately 132 mm) between the baseline and 2070.

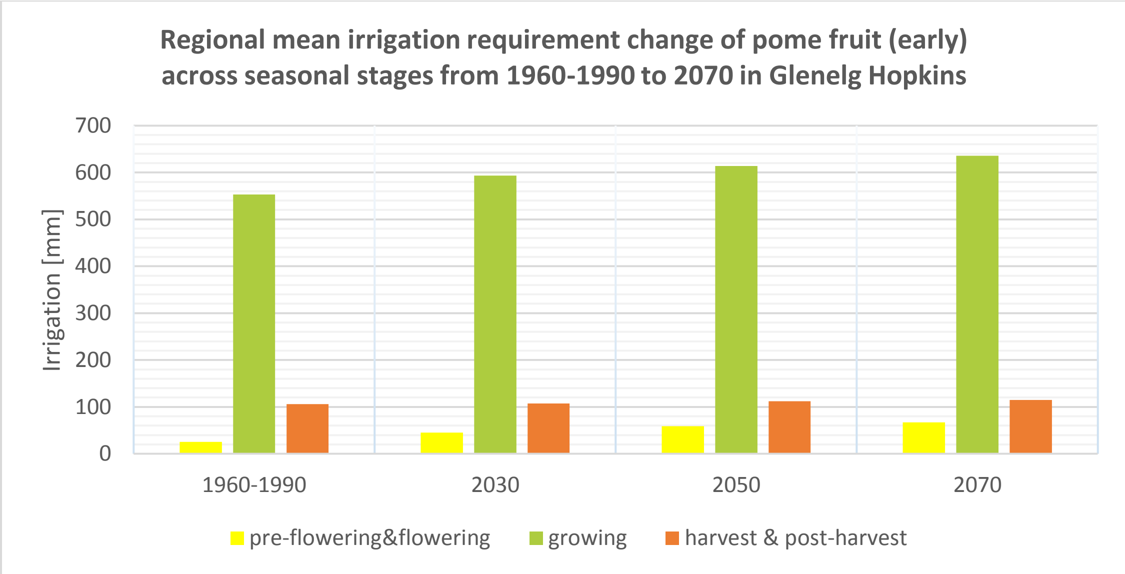

Figure 19 - Regional change in Irrigation requirement for pome fruit (early varieties) between baseline, 2030, 2050 and 2070

Figure 20 presents land suitability maps for early varieties of pome fruit accompanied by a suitability change diagram in Figure 21. In terms of water use, suitability between 1960-1990 and 2070 is due to decrease, with virtually unchanged values in the north but high irrigation requirement in the central parts of the catchment and its south causing suitability to drop. Chill units are likely to decrease, although staying high enough to allow sufficient vernalisation. Suitability in terms of temperature is rather low across the region and projected to decrease, especially in the north. Overall suitability for early varieties of pome fruit is due to decrease by 4.9% between the baseline and 2070. As mentioned in previous sections, even though the projected increase in extreme weather events is likely to have a negative impact on pome fruit production, it could not be accounted for in this study due to the unpredictability of their incidence as well as the nature of the LSA model.

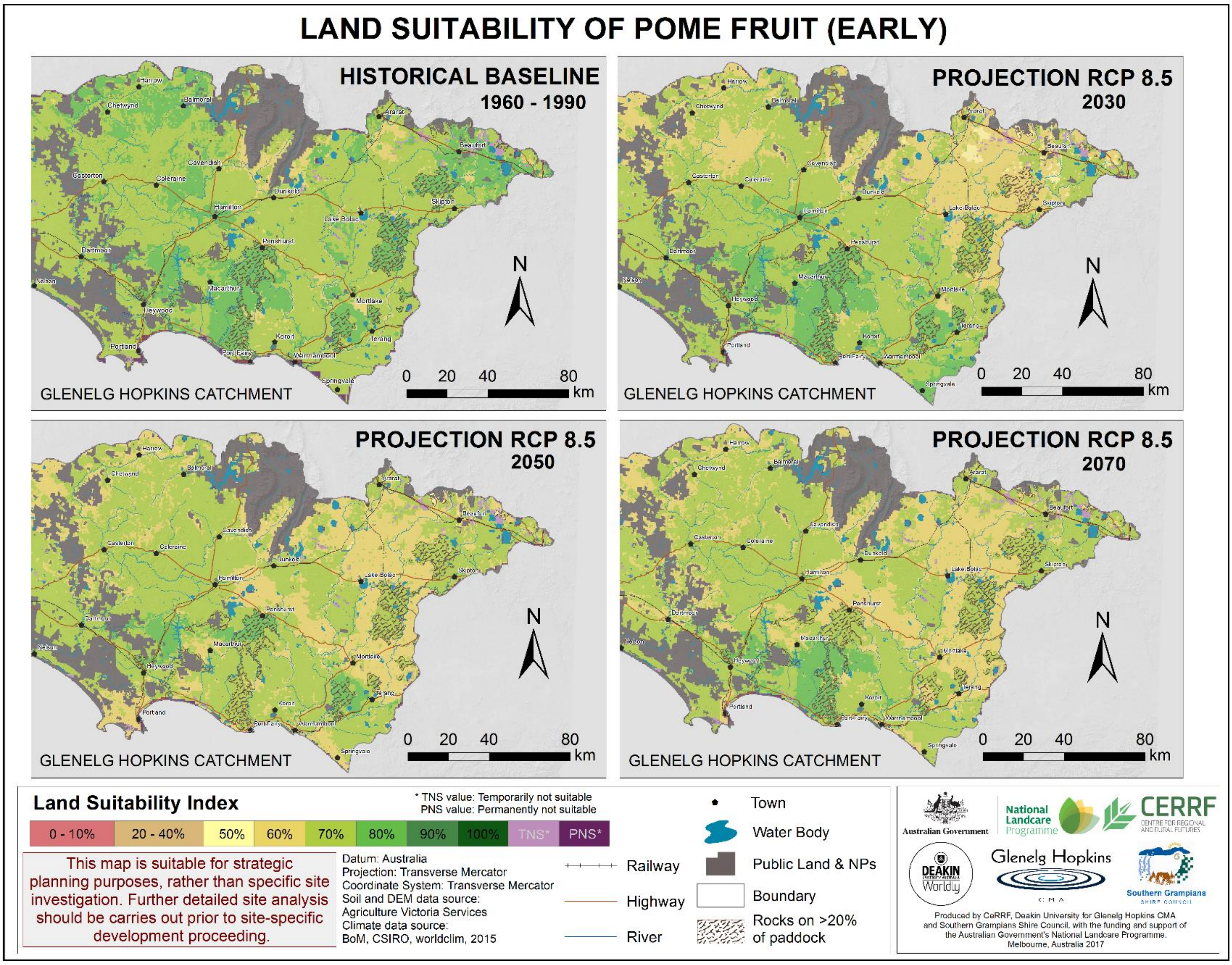

Figure 20 – Land suitability maps of early varieties of pome fruit in Glenelg Hopkins region

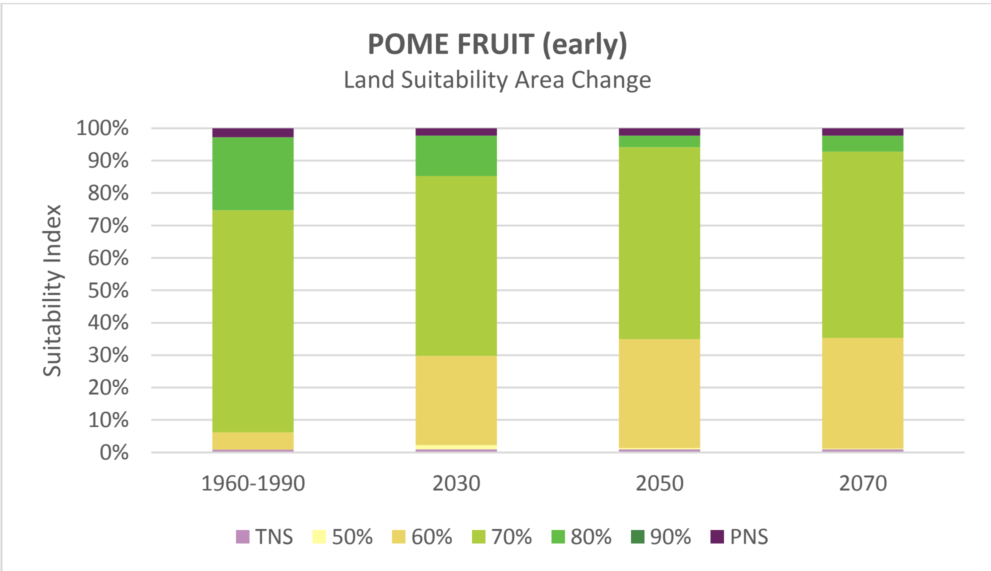

Figure 21 – Land suitability area change of early varieties of pome fruit

Pome Fruit (late)

Diagrams specifying the timing of maturing for different pome fruit varieties can be found in Appendix II, early maturing examples are: apples – *Granny Smith, Cripps Pink*; pears – *Williams', Winter Nelis*.

Figure 22 shows the change of seasonal irrigation requirement based on a mean of all regional values. Due to the aforementioned likely increase in evapotranspiration and decrease in effective rainfall, pome fruit is projected to need more irrigation to support its production. The warmer stages of the growing season (summer-early autumn) require the highest amount of irrigation (increasing the most between the baseline and 2070). The mean irrigation requirement of early pome fruit is projected to change by 16.6% (approximately 166 mm) between the baseline and 2070.

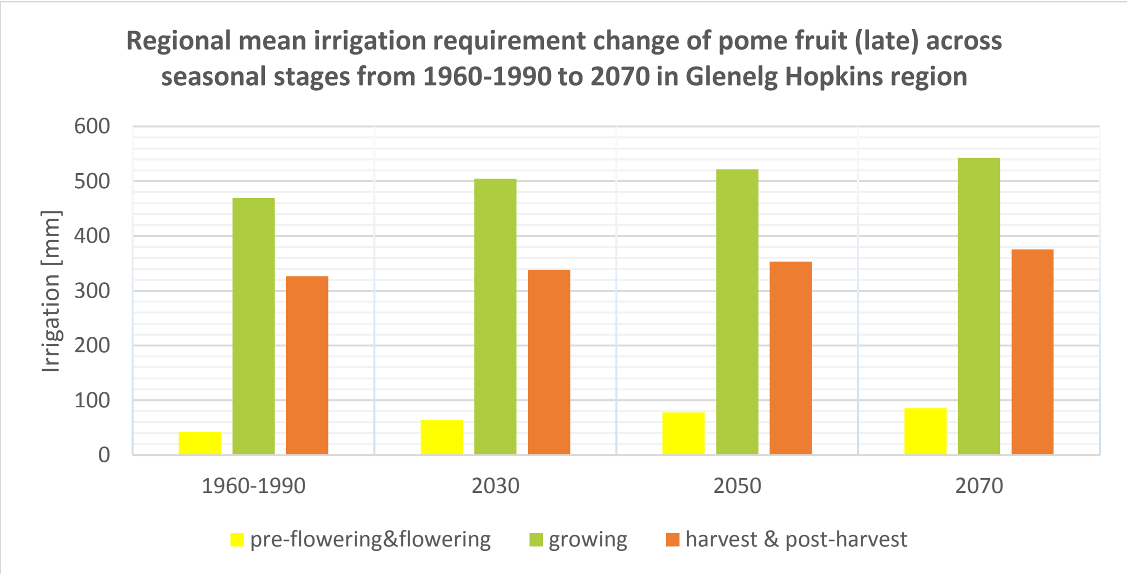

Figure 22 - Regional change in Irrigation requirement for pome fruit (late varieties) between baseline, 2030, 2050 and 2070

Figure 23 presents land suitability maps for late varieties of pome fruit accompanied by a suitability change diagram in Figure 24. Similarly to the early varieties of pome fruit, the amount of chilling units stays above 500 chill hours, allowing for sufficient vernalisation. Land suitability in terms of water use increases in the future, especially in the south where it reaches high suitability index values while staying medium in the north. With an increase in mean temperature, late varieties are more likely to ripen and suitability therefore increases. As apparent from the suitability maps, overall suitability of late varieties of pome fruit is likely to increase in the future by 11.3% between the baseline and 2070. As mentioned in previous sections, even though the projected increase in extreme weather events is likely to have a negative impact on pome fruit production, it could not be accounted for in this study due to the unpredictability of their incidence as well as the nature of the LSA model.

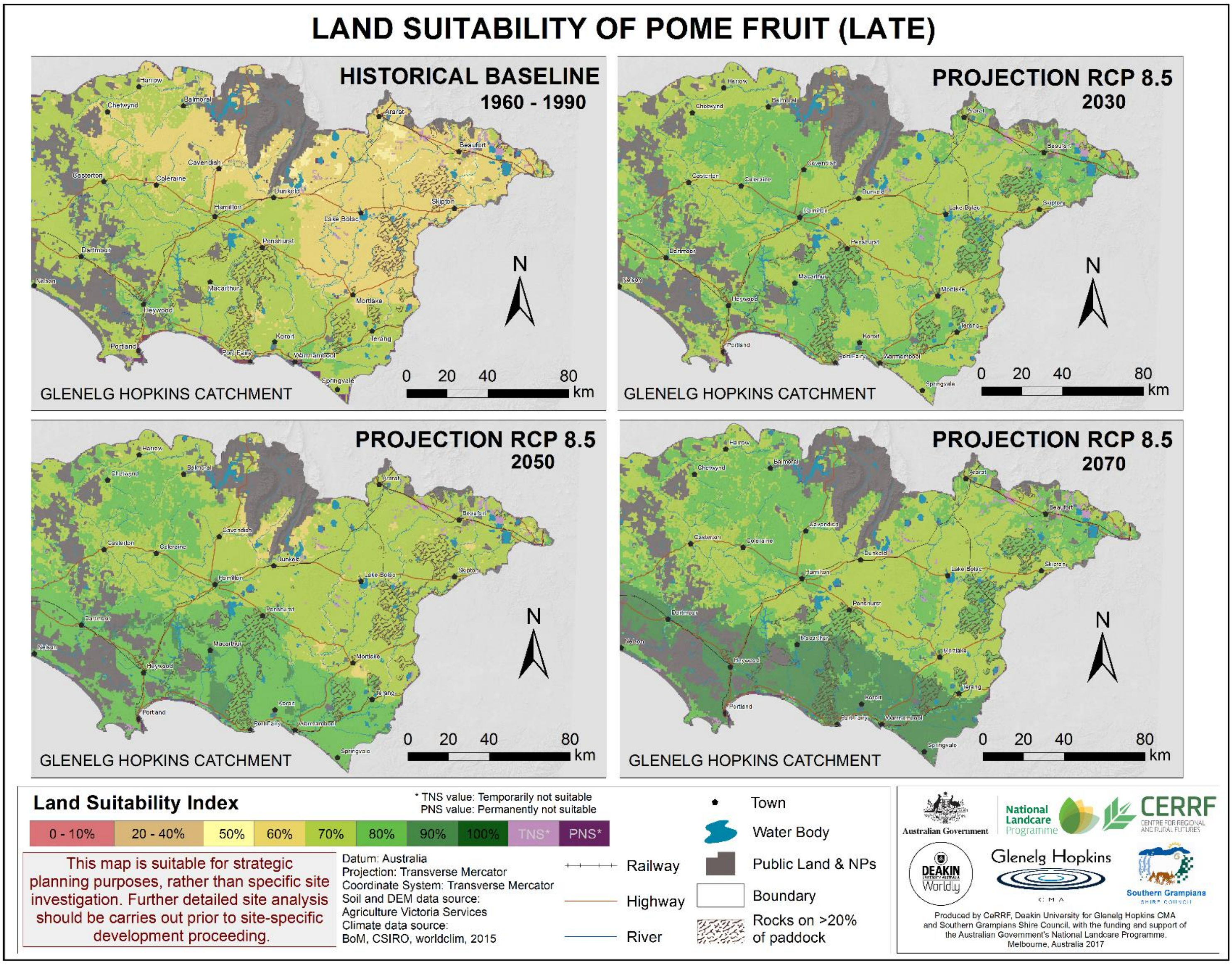

Figure 23 – Land suitability maps of late varieties of pome fruit Glenelg Hopkins region

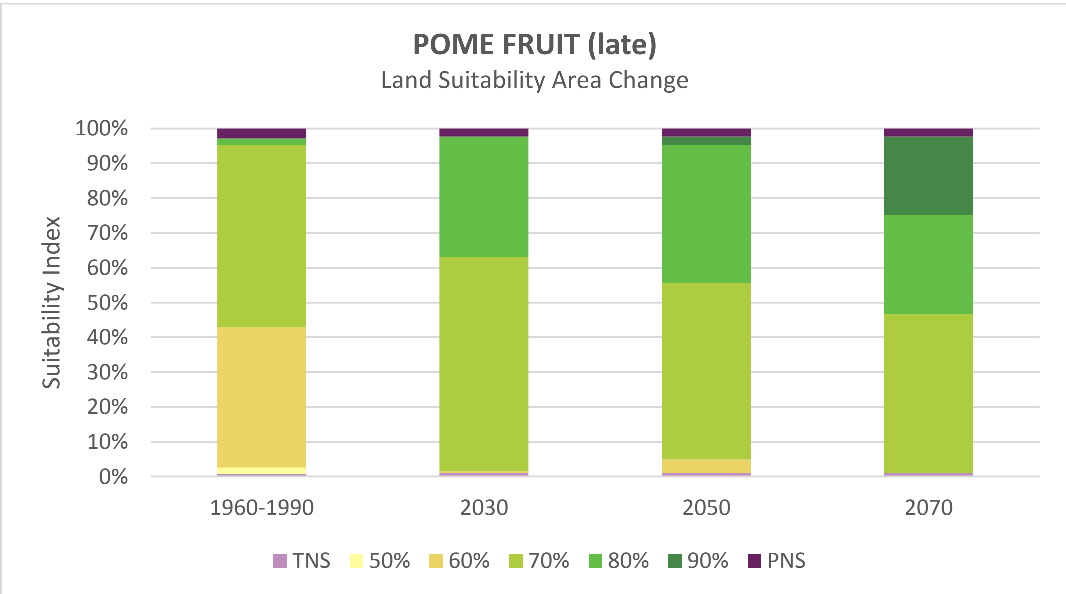

Figure 24 – Land suitability area change of late varieties of pome fruit

C. Citrus

Citrus is an important fruit industry in Australia, with major growing areas being traditionally situated in warmer regions of NSW, WA or QLD. This model is based on growing requirements of lemons detailed below. Water availability, temperature and wind are the two most important climate factors influencing growth. Lemons and limes are very sensitive to frost, and they should therefore be planted in areas with winter temperatures falling below -4°C. Other citrus varieties such as oranges are more frost tolerant. The optimum temperature for growth is 25-30°C, temperatures below 25°C have lower rate of photosynthesis while temperature above 40°C stunt growth. Oranges are less tolerant to heat than lemons (Hardy 2004; Department of Agriculture and Fisheries: Queensland Government 2016). Due to high sensitivity to wind, strong or cold winds cause a reduction in yields and lower fruit quality by bruising.

Citrus trees require a range of nurients in the soils, the level or concentration of which can affect vigour, health and yield. Citrus does not like very acid soils of pH_{Ca} below 5 (all temporarily not suitable areas) or very alkalike above 8. Teh preferered pH_{Ca} is 6.0-7.0. They require well structured soils with lighter texture, good drainage and topsoil of at least 0.6m (Department of Agriculture and Fisheries: Queensland Government 2016; Revelant et al. 2004).

Gentle slopes facing north are desirable for the growth of citrus trees. Slopes with a south facing aspect are generally colder and hence more prone to frost; they may also not be warm enough in spring to allow for bees to actively pollinate the flowers. Slopes with a north aspect are ideal as they capture more light and hence are warmer. A slight and gentle slope is optimal for citrus fruit trees as this can aid in air drainage. This is particularly important in areas with incidences of spring frosts, a slope will allow cold air to drain away from the orchard into lower areas preventing any frost damage. Low lying areas, for this reason, should be avoided, as these regions can trap colder air which can increase incidences of frost occurring. Steep slopes should be avoided to reduce the risk of soil erosion and nutrient runoff.

Figure 25 shows the change of seasonal irrigation requirement based on a mean of all regional values. Despite the aforementioned likely increase in evapotranspiration and decrease in effective rainfall, the irrigation need of citrus is projected to decline. The warmer stages of the growing season (summer-early autumn) require the highest amount of irrigation. The mean irrigation requirement of citrus is projected to change by 23.8% (decreasing by approximately 73 mm) between the baseline and 2070.

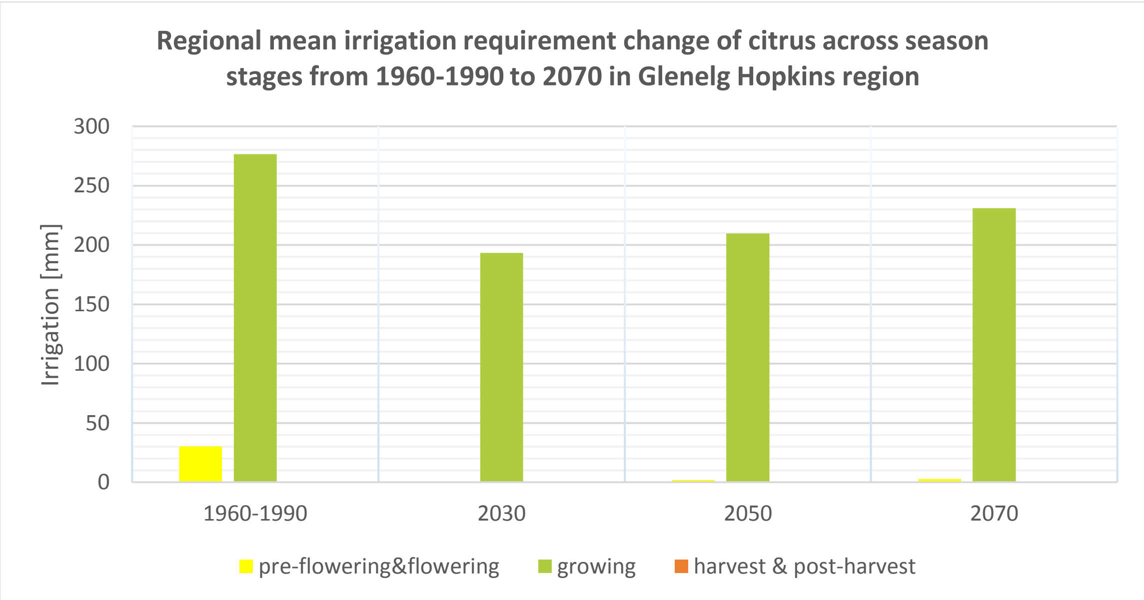

Figure 25- Regional change in Irrigation requirement for citrus between baseline, 2030, 2050 and 2070

Figure 26 presents land suitability maps for citrus accompanied by a suitability change diagram in Figure 27. Suitability in terms of water use increases in the future from low to medium, with the biggest change in the north. Temperatures are projected to be get higher, increasing the suitability across the region, and especially in the north. The overall suitability of citrus is projected to increase by 9.2%, staying in the medium index range, as apparent on the maps below. As mentioned in previous sections, even though the projected increase in extreme weather events is likely to have a negative impact on citrus production, it could not be accounted for in this study due to the unpredictability of their incidence as well as the nature of the LSA model.

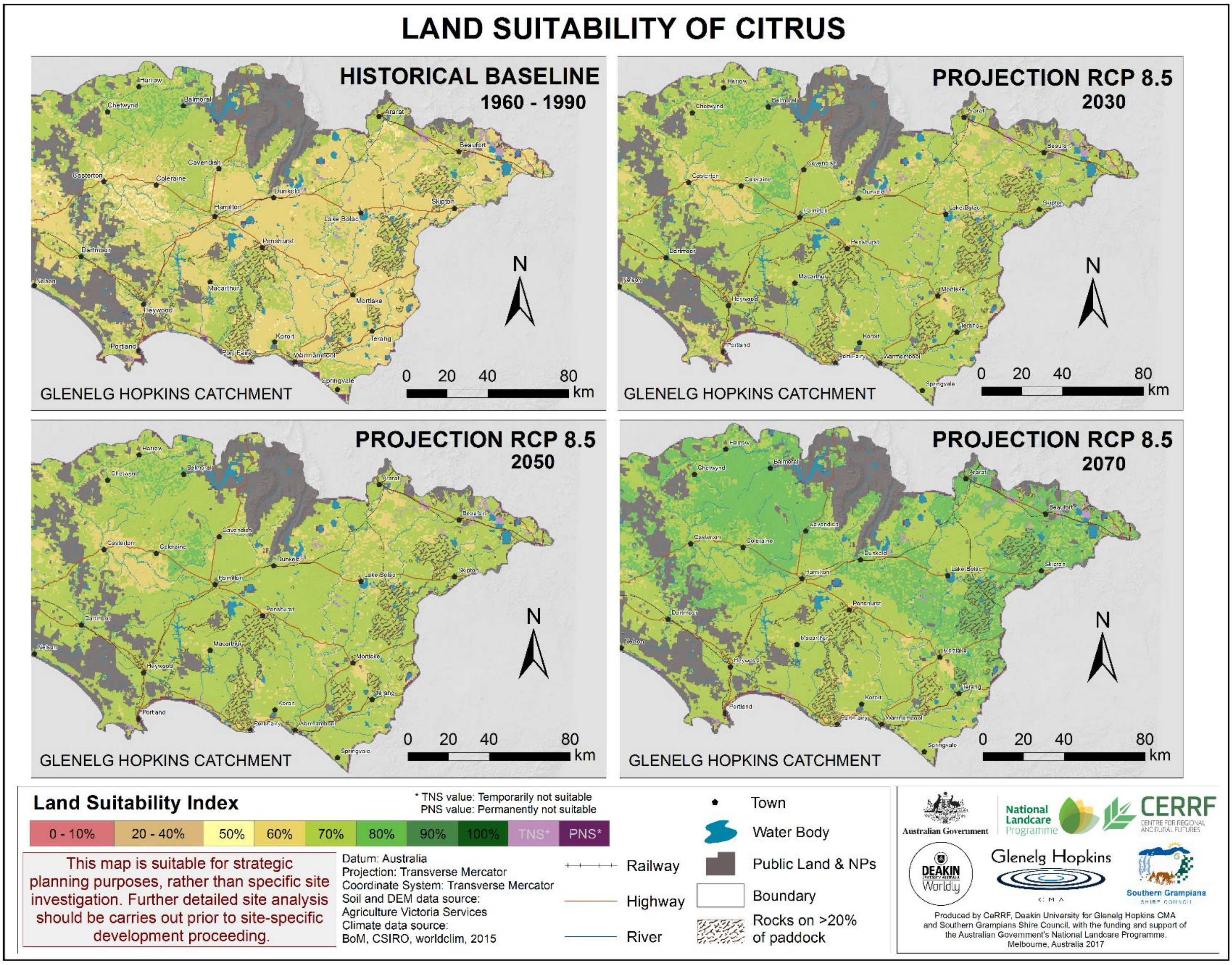

Figure 26 – Land suitability maps of citrus in Glenelg Hopkins region

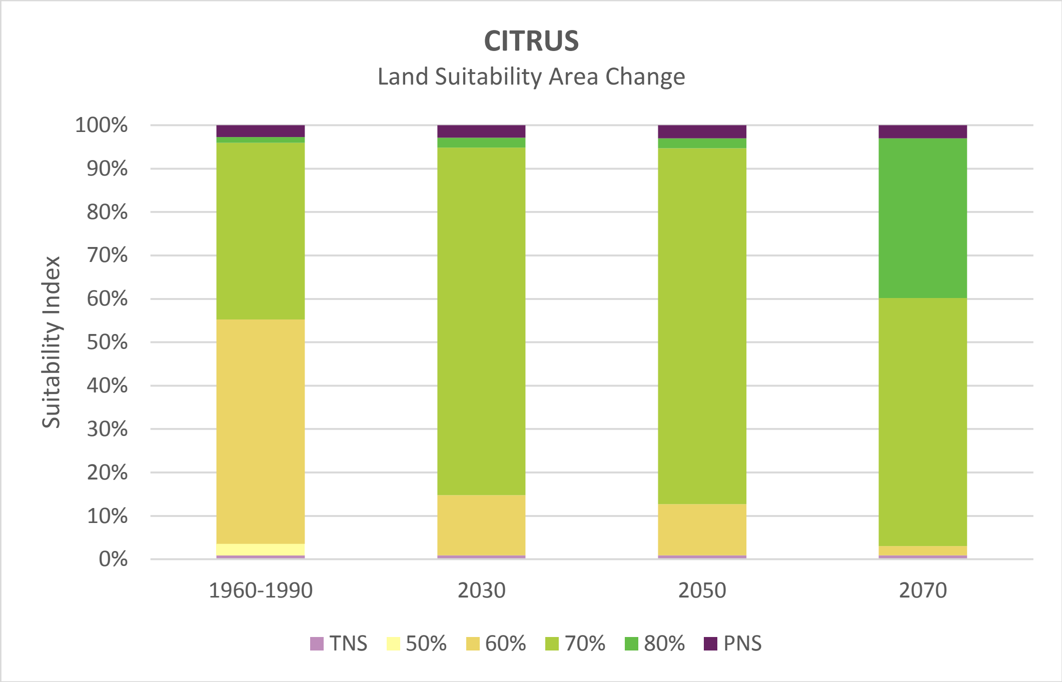

Figure 27 – Land suitability change of citrus

D. Berries

This report based the LSA model of berries on raspberries and other cane fruit. There are many varieties of berries, which, along with climate, influence the timing of their growth stages. The growth cycle stages have been set to accommodate for both *Floricane* and *Primocane* varieties, flowering has therefore been set between September and November, and harvest between January and April.

The primary climate factors influencing cane fruit are temperature at key growth stages and dry conditions at harvest (Buntain & Sparrow 2012; Agriculture Victoria 2013). Similarly to pome and stone fruit trees, berries also need adequate chilling (>800 hill hours between 0°C and 7°C) (Buntain & Sparrow 2012) to overcome dormancy. Plants that are flowering or carry young fruit have low tolerance to frost that decreases yield. So do high temperatures (extended periods over 30°C) or rainfall during harvest, causing damage to the berries.

Berries prefer a well-drained site with soil depth of at least 25cm. Ideal soil has a pH_{Ca} of 5.5-6.5 and no salinity. Soils with heavy subsoil or rocky layer are not suitable (Buntain & Sparrow 2012; Agriculture Victoria 2013). Gentle slopes facing north are desirable for the growth of berries. Slopes in general are not a concern, but slopes with a south facing aspect are generally colder and hence more prone to frost. Slopes with a north aspect are ideal as they capture more light and hence are warmer. A slight and gentle slope is optimal for berries as this can aid in air drainage. This is particularly important in areas with incidences of spring frosts, a slope will allow cold air to drain away from the plantings into lower areas preventing any frost damage. Low lying areas, for this reason, should be avoided, as these regions can trap colder air which can increase incidences of frost occurring. Steep slopes should be avoided to reduce the risk of soil erosion and nutrient runoff. Aspect can be important, depending on the most prevalent direction of wind, since hot and dry winds cause damage to the fruit. The output land suitability maps reflect a model strictly based on biophysical factors, windbreaks or tunnels used by growers, sheltering their crops from weather extremes could therefore not be accounted for.

Figure 28 shows the change of seasonal irrigation requirement based on a mean of all regional values. Due to the aforementioned likely increase in evapotranspiration and decrease in effective rainfall, berries are projected to need more irrigation to support their production. The warmer stages of the growing season (summer-early autumn) require the highest amount of irrigation (increasing the most between the baseline and 2070). The mean irrigation requirement of cane fruit is projected to change by 16.3% (approximately 155 mm) between the baseline and 2070.

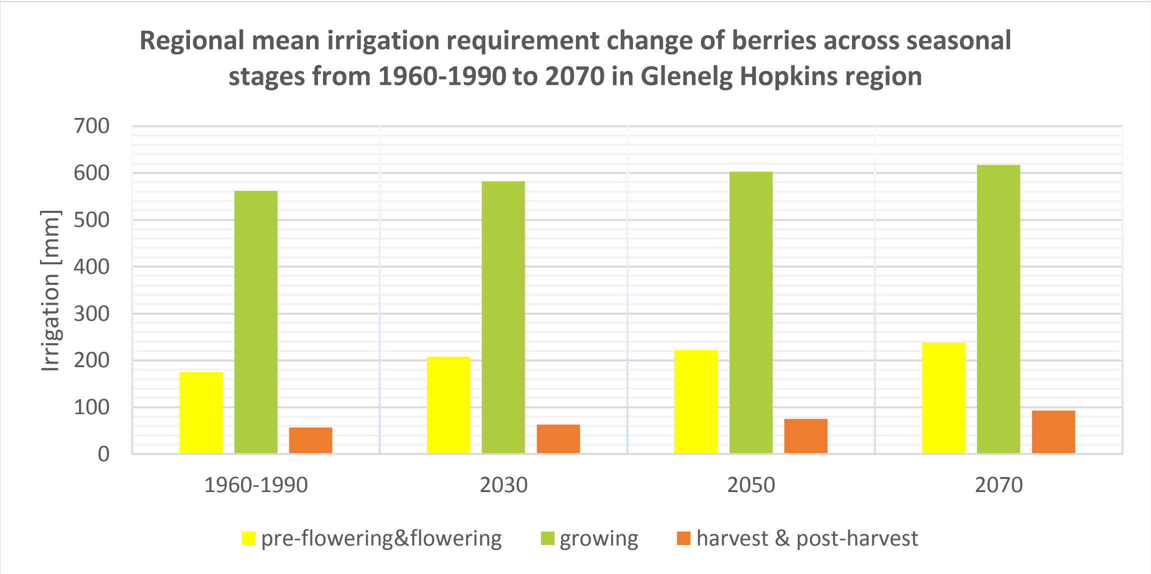

Figure 28 - Regional change in Irrigation requirement for berries between baseline, 2030, 2050 and 2070

Figure 29 presents land suitability maps for berries accompanied by a suitability change diagram in Figure 30. Land suitability in terms of water use stays the same throughout the time series, at high suitability range. The amount of chilling in 1960-1990 is above the optimum, but decreases to the optimum range of 800-1600 chill hours between 2030 and 2050, after which it drops below 800 and decreases the suitability slightly in 2070. With temperature suitability for the growth and maturing of cane fruit increasing across the region, the overall suitability is also likely to increase by 7.6% between 1960-1990 and 2070. As mentioned in previous sections, even though the projected increase in extreme weather events may have a negative impact on cane fruit production, it could not be accounted for in this study due to the unpredictability of their incidence, shelters used by the growers as well as the nature of the LSA model.

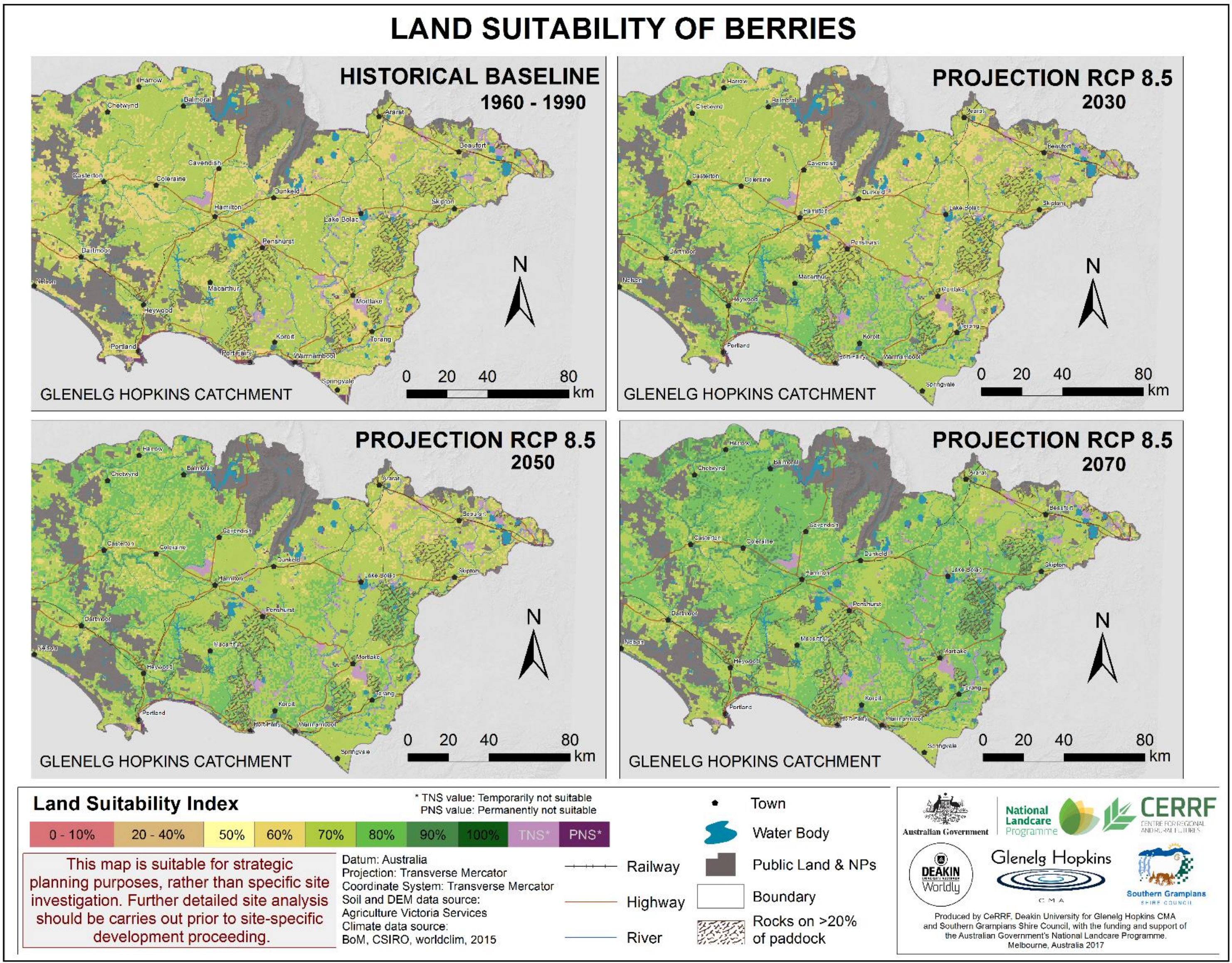

Figure 29 – Land suitability maps of berries in Glenelg Hopkins region

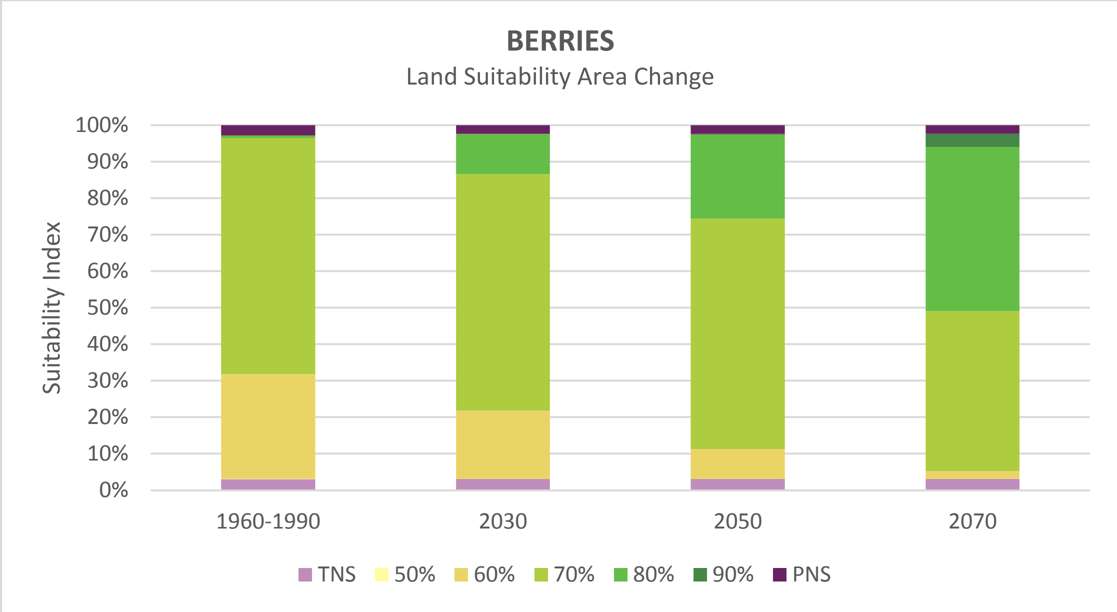

Figure 30 – Land suitability change of berries

13. Concluding remarks

This report has been structured in several components, with a focus on the likely impacts of climate change on the pasture growth of early and late varieties of pome fruit, stone fruit, citrus and berries in the Glenelg Hopkins catchment. Figure 31 Figure 31 shows the overall trends in land suitability, indicating that early stone fruit, late pome fruit, citrus and berries are likely to become more suitable, whereas the suitability of late stone fruit and early pome fruit is projected to decline. The overall median suitability index for fruit in Glenelg Hopkins region is 69.4% for baseline 1960-1990 likely to increase to approx. 74.1% by 2070 (an average increase in suitability for pastures excluding ryegrass is 4.7% by 2070).

In general, the increase in mean temperature is likely to stimulate ripening of fruit, but the accompanying decline in chill accumulation can cause insufficient vernalisation. Weather extremes such as frost, heat, hail or wind and storm activity are likely to negatively impact yields. Irrigation is required for all modelled commodities, with the irrigation requirement increasing out to 2070 due to higher evapotranspiration and lower effective rainfall. The necessity of horticultural commodities to be irrigated negatively impacts on their suitability for the Glenelg Hopkins region due to the currently limited access to water suitable for irrigation, especially in the north-west part of the catchment. Southern part of Glenelg Hopkins region and areas around Ballarat and Colac have access to good quality ground water, making them more likely to be able to support horticultural industry. Compared to broadacre crops and hay from pastures, fruit is highly perishable, and as such requires adequate chilling facilities, careful handling during harvest, storage and transport. The quality of infrastructure and distance to market or processing plants are of paramount importance in terms of product quality.

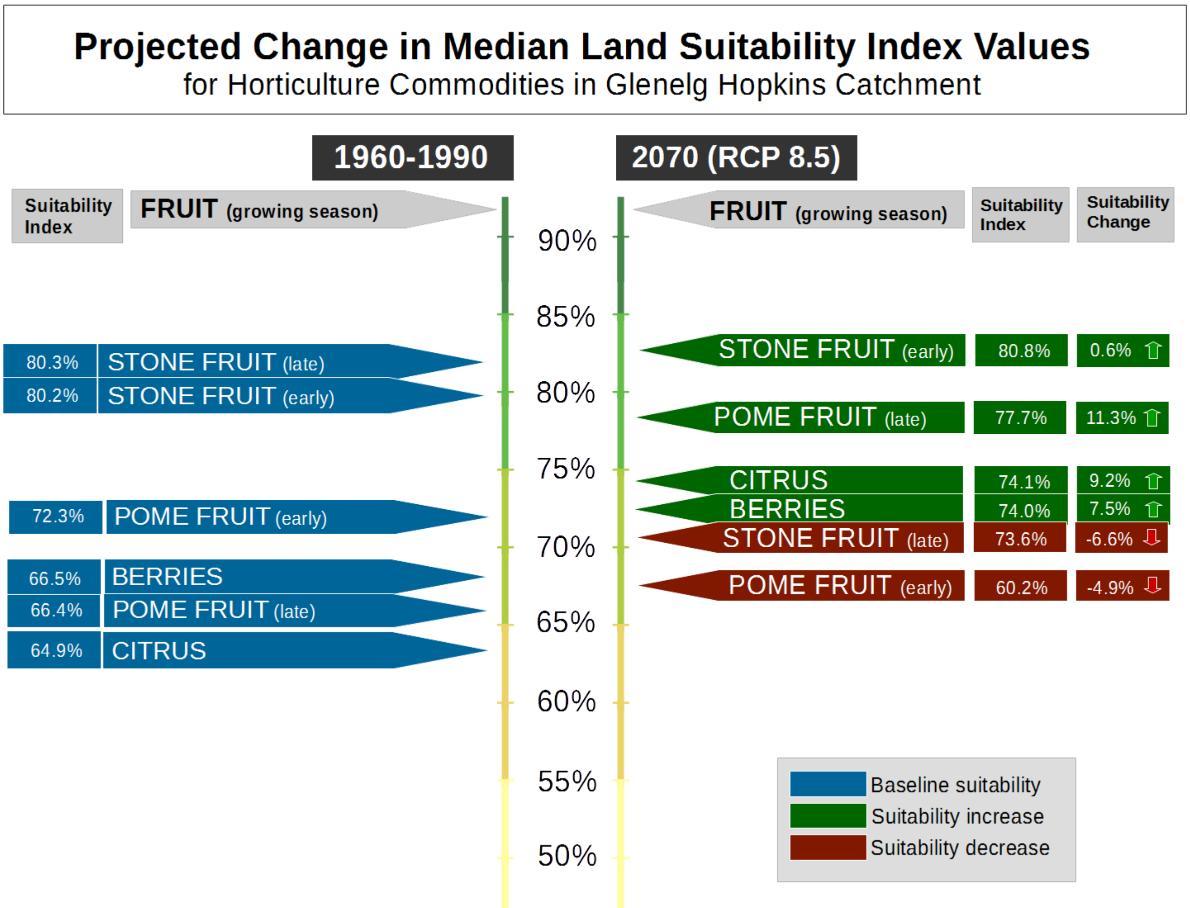

Figure 31 – Projected change in median land suitability index values for horticulture

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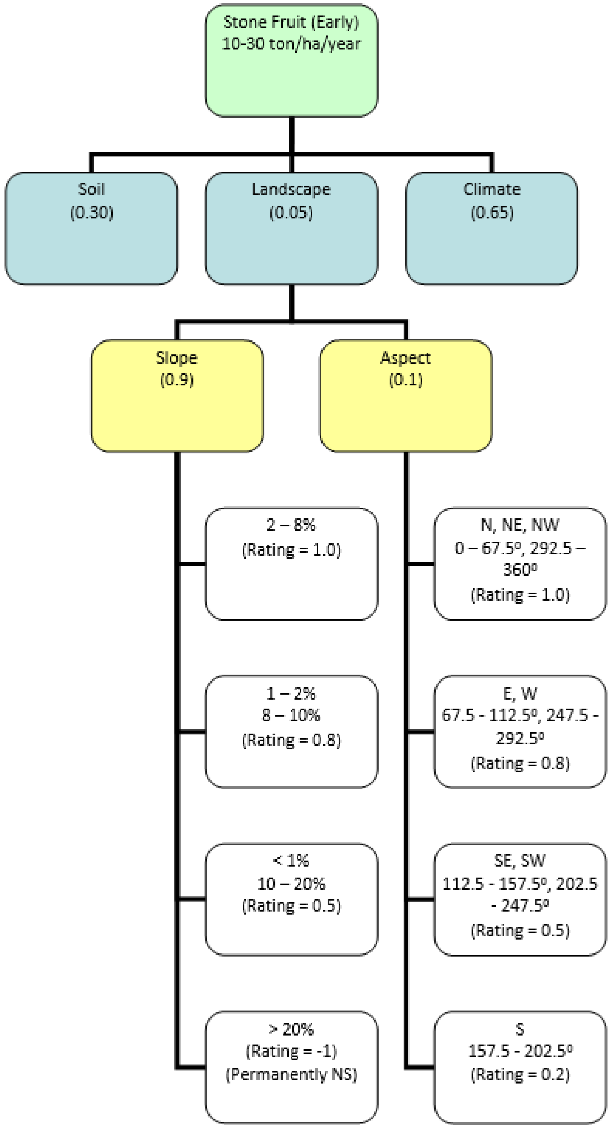
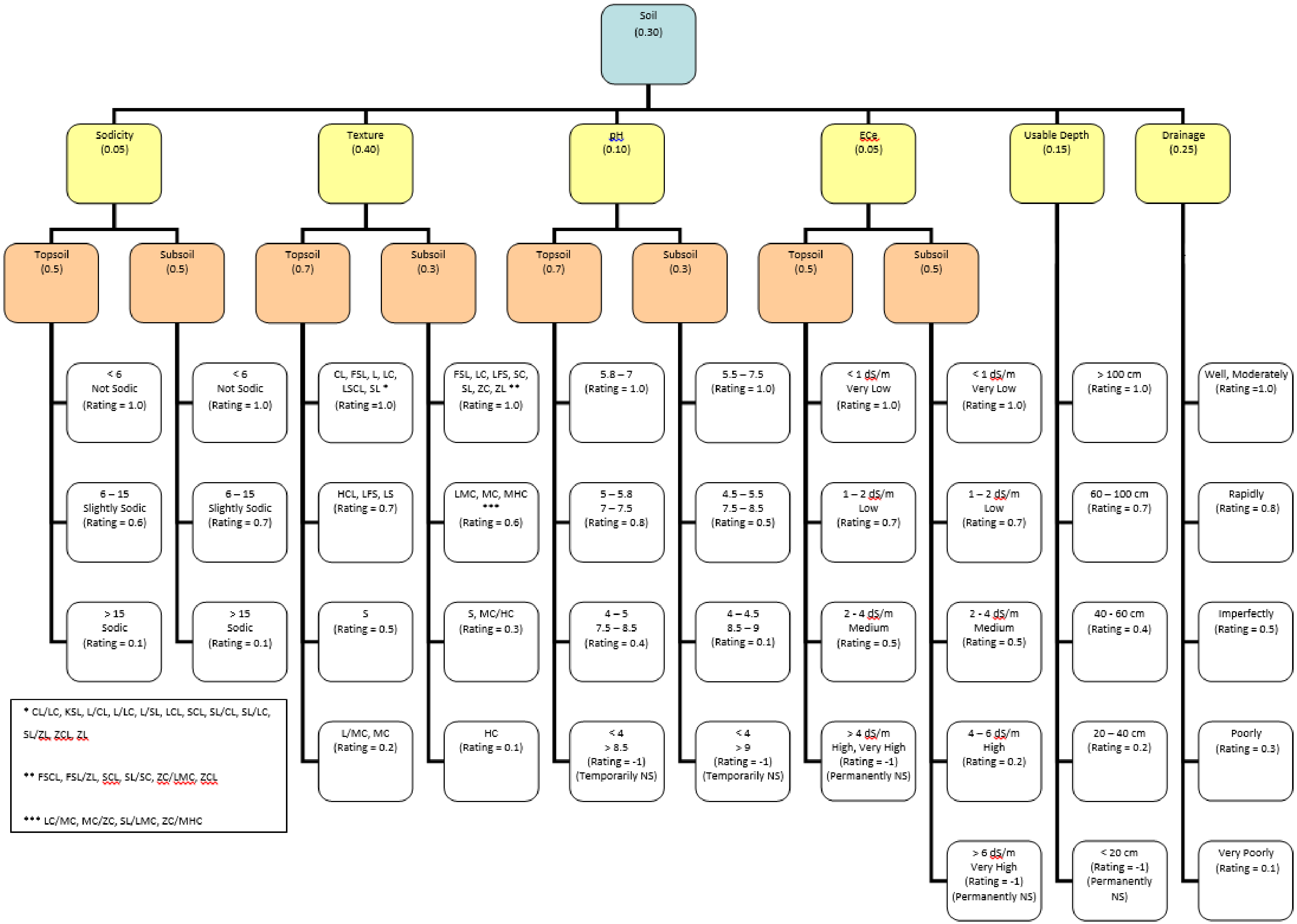
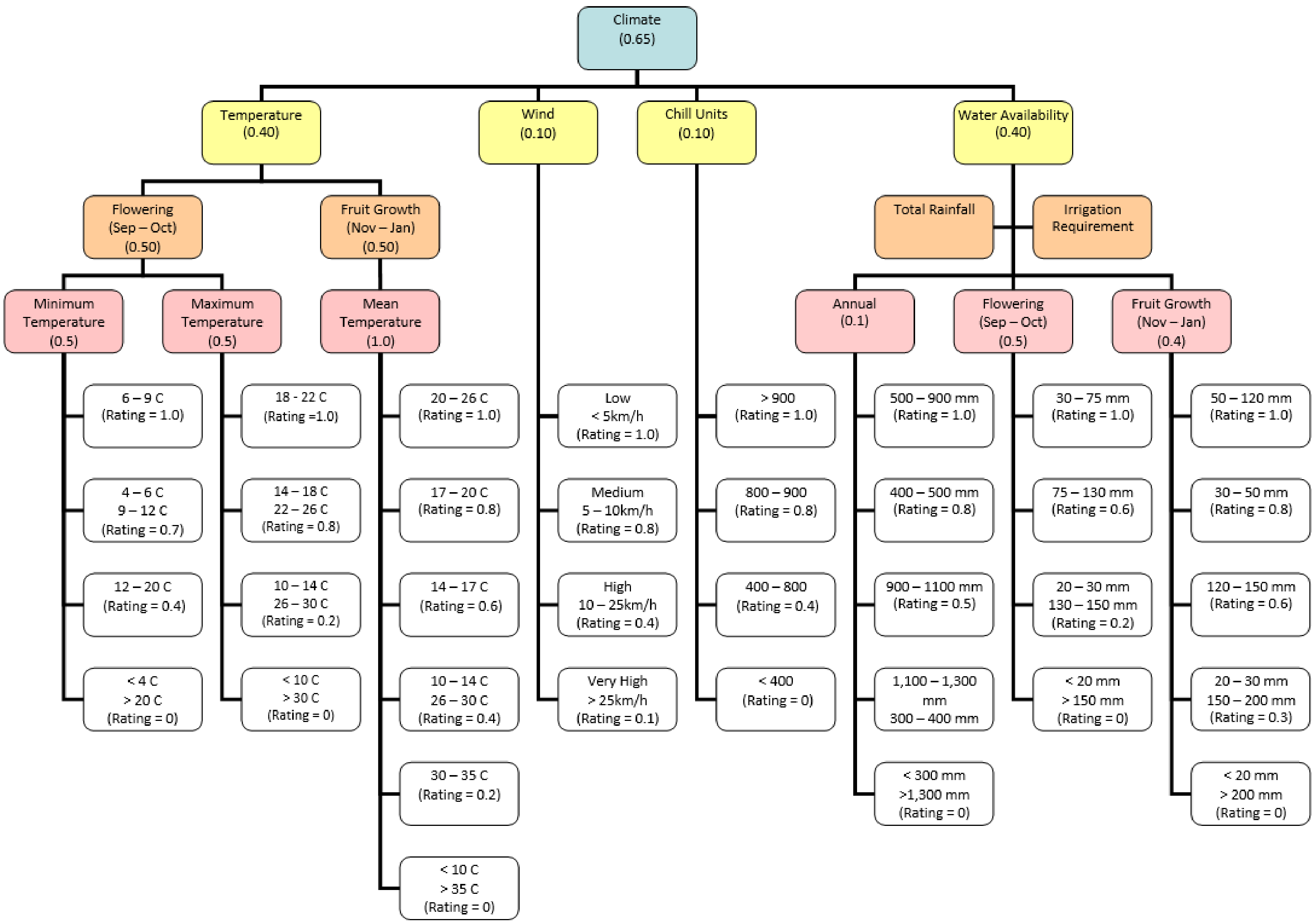
Appendix I – Stone Fruit (early varieties) hierarchy





Soil (0.30)
Sodicity (0.05)
Texture (0.40)
pH (0.10)
ECe (0.05)
Usable Depth (0.15)
Drainage (0.25)
Topsoil (0.5)
Subsoil (0.5)
Topsoil (0.7)
Subsoil (0.3)
Topsoil (0.7)
Subsoil (0.3)
Topsoil (0.5)
Subsoil (0.5)
< 6 Not Sodic (Rating = 1.0)
6 – 15 Slightly Sodic (Rating = 0.6)
> 15 Sodic (Rating = 0.1)
< 6 Not Sodic (Rating = 1.0)
6 – 15 Slightly Sodic (Rating = 0.7)
> 15 Sodic (Rating = 0.1)
CL, FSL, L, LC, LSCL, SL * (Rating =1.0)
HCL, LFS, LS (Rating = 0.7)
S (Rating = 0.5)
L/MC, MC (Rating = 0.2)
FSL, LC, LFS, SC, SL, ZC, ZL ** (Rating = 1.0)
LMC, MC, MHC *** (Rating = 0.6)
S, MC/HC (Rating = 0.3)
HC (Rating = 0.1)
5.8 – 7 (Rating = 1.0)
5 – 5.8 7 – 7.5 (Rating = 0.8)
4 – 5 7.5 – 8.5 (Rating = 0.4)
< 4 > 8.5 (Rating = -1) (Temporarily NS)
5.5 – 7.5 (Rating = 1.0)
4.5 – 5.5 7.5 – 8.5 (Rating = 0.5)
4 – 4.5 8.5 – 9 (Rating = 0.1)
< 4 > 9 (Rating = -1) (Temporarily NS)
< 1 dS/m Very Low (Rating = 1.0)
1 – 2 dS/m Low (Rating = 0.7)
2 - 4 dS/m Medium (Rating = 0.5)
> 4 dS/m High, Very High (Rating = -1) (Permanently NS)
< 1 dS/m Very Low (Rating = 1.0)
1 – 2 dS/m Low (Rating = 0.7)
2 - 4 dS/m Medium (Rating = 0.5)
4 – 6 dS/m High (Rating = 0.2)
> 6 dS/m Very High (Rating = -1) (Permanently NS)
> 100 cm (Rating = 1.0)
60 – 100 cm (Rating = 0.7)
40 - 60 cm (Rating = 0.4)
20 – 40 cm (Rating = 0.2)
< 20 cm (Rating = -1) (Permanently NS)
Well, Moderately (Rating =1.0)
Rapidly (Rating = 0.8)
Imperfectly (Rating = 0.5)
Poorly (Rating = 0.3)
Very Poorly (Rating = 0.1)
* CL/LC, KSL, L/CL, L/LC, L/SL, LCL, SCL, SL/CL, SL/LC, SL/ZL, ZCL, ZL
** FSCL, FSL/ZL, SCL, SL/SC, ZC/LMC, ZCL
*** LC/MC, MC/ZC, SL/LMC, ZC/MHC

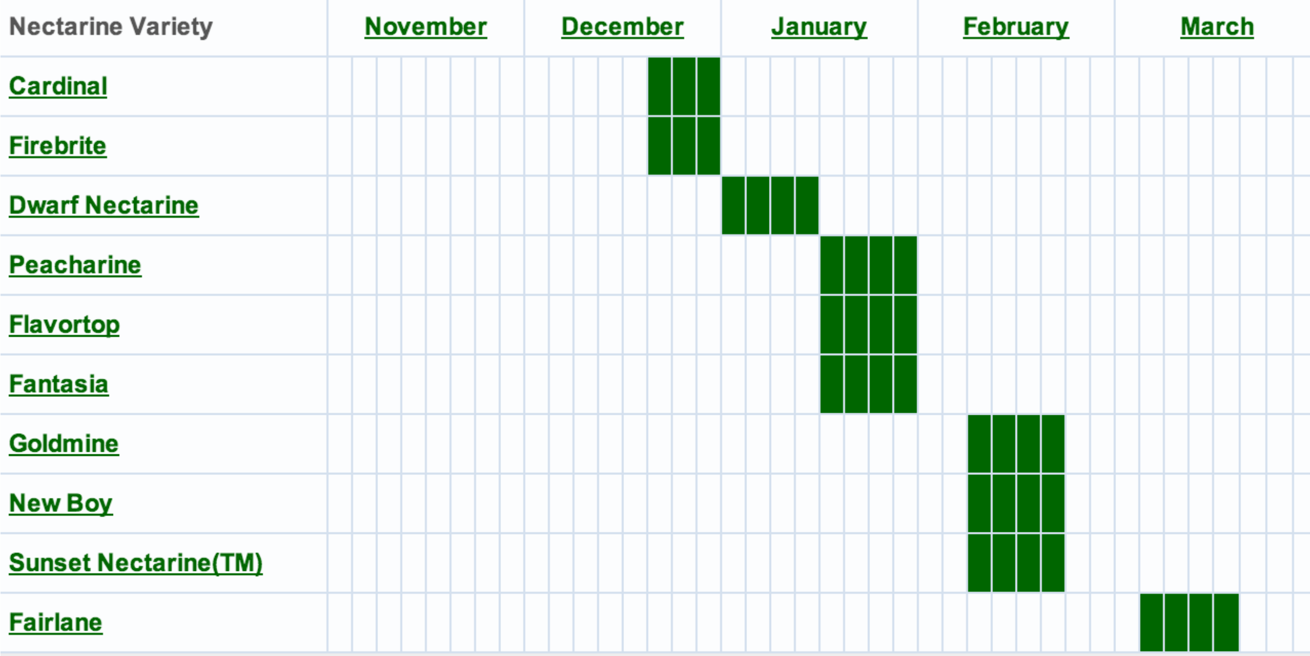


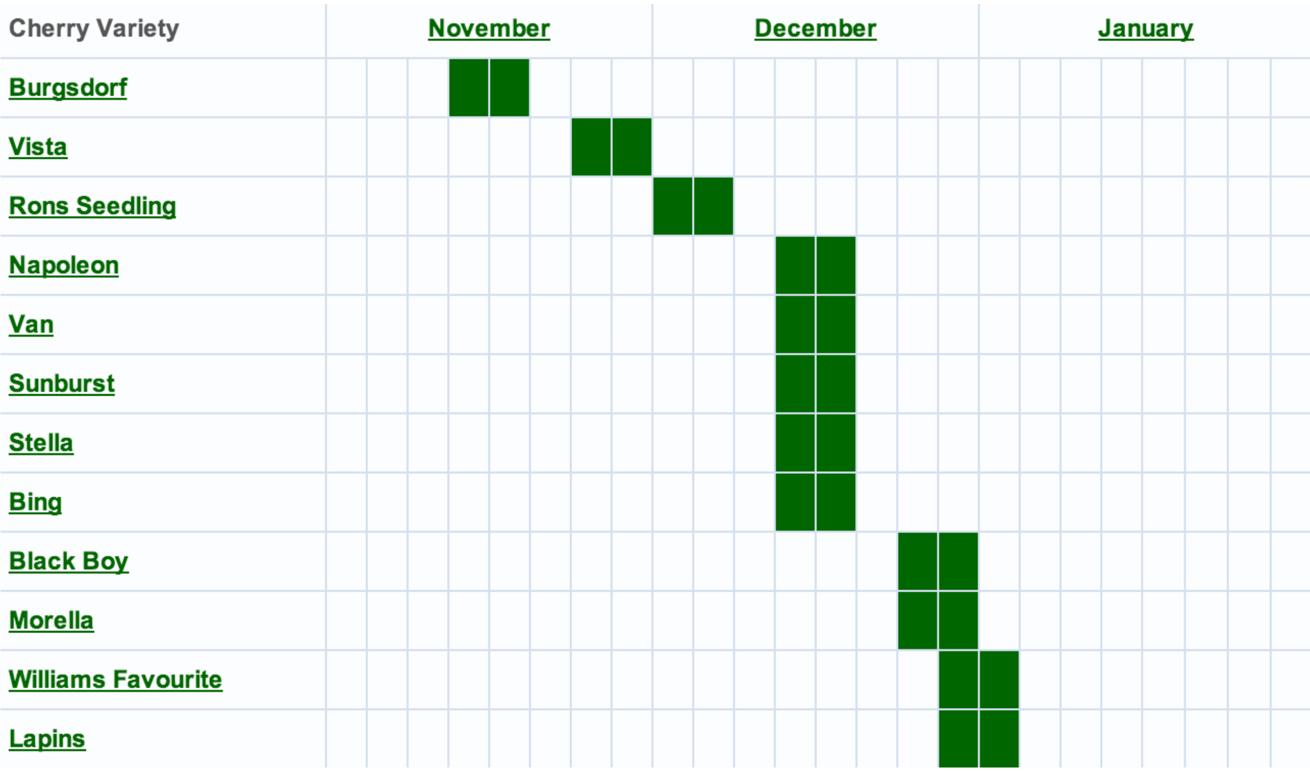
Climate (0.65)
Temperature (0.40)
Wind (0.10)
Chill Units (0.10)
Water Availability (0.40)
Flowering (Sep – Oct) (0.50)
Fruit Growth (Nov – Jan) (0.50)
Total Rainfall
Irrigation Requirement
Minimum Temperature (0.5)
Maximum Temperature (0.5)
Mean Temperature (1.0)
Annual (0.1)
Flowering (Sep – Oct) (0.5)
Fruit Growth (Nov – Jan) (0.4)
6 – 9 C (Rating = 1.0)
4 – 6 C 9 – 12 C (Rating = 0.7)
12 – 20 C (Rating = 0.4)
< 4 C > 20 C (Rating = 0)
18 - 22 C (Rating =1.0)
14 – 18 C 22 – 26 C (Rating = 0.8)
10 – 14 C 26 – 30 C (Rating = 0.2)
< 10 C > 30 C (Rating = 0)
20 – 26 C (Rating = 1.0)
17 – 20 C (Rating = 0.8)
14 – 17 C (Rating = 0.6)
10 – 14 C 26 – 30 C (Rating = 0.4)
30 – 35 C (Rating = 0.2)
< 10 C > 35 C (Rating = 0)
Low < 5km/h (Rating = 1.0)
Medium 5 – 10km/h (Rating = 0.8)
High 10 – 25km/h (Rating = 0.4)
Very High > 25km/h (Rating = 0.1)
> 900 (Rating = 1.0)
800 – 900 (Rating = 0.8)
400 – 800 (Rating = 0.4)
< 400 (Rating = 0)
500 – 900 mm (Rating = 1.0)
400 – 500 mm (Rating = 0.8)
900 – 1100 mm (Rating = 0.5)
1,100 – 1,300 mm 300 – 400 mm
< 300 mm >1,300 mm (Rating = 0)
30 – 75 mm (Rating = 1.0)
75 – 130 mm (Rating = 0.6)
20 – 30 mm 130 – 150 mm (Rating = 0.2)
< 20 mm > 150 mm (Rating = 0)
50 – 120 mm (Rating = 1.0)
30 – 50 mm (Rating = 0.8)
120 – 150 mm (Rating = 0.6)
20 – 30 mm 150 – 200 mm (Rating = 0.3)
< 20 mm > 200 mm (Rating = 0)

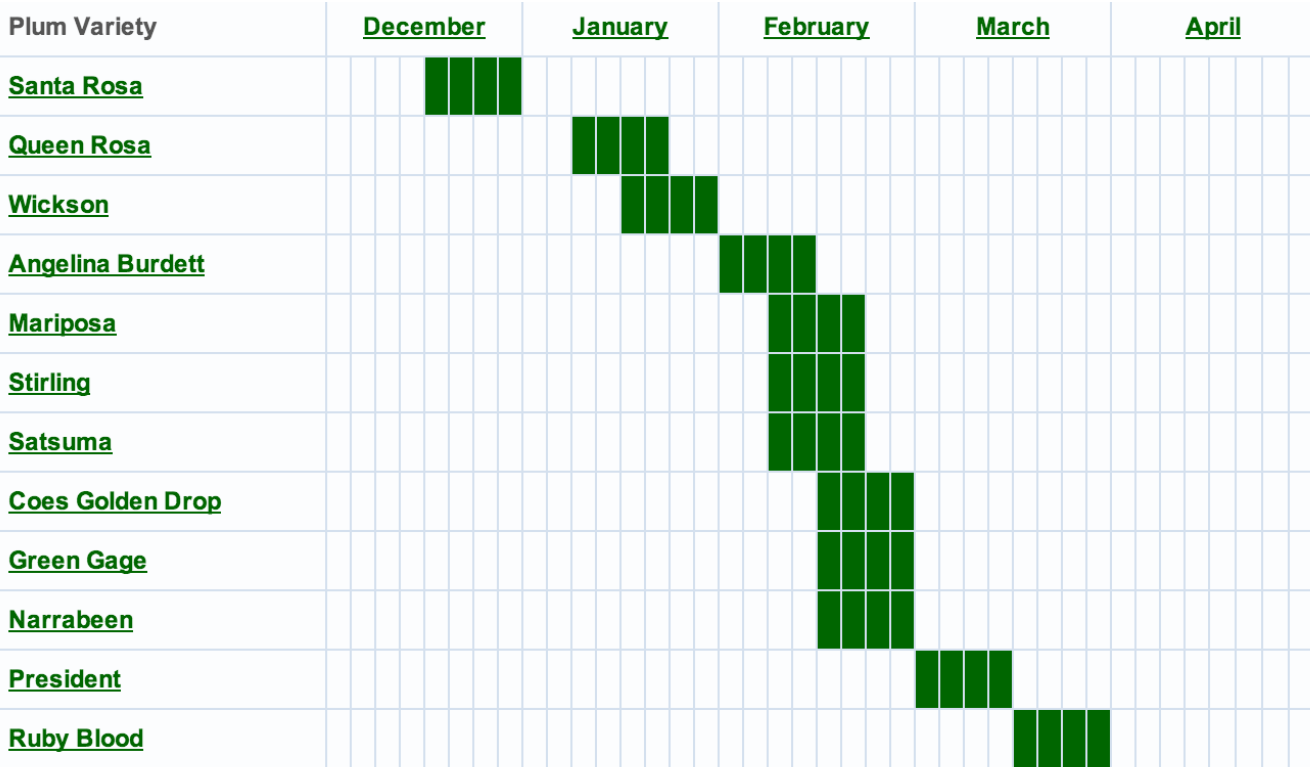
Appendix II – Ripening times based on South Australia

(source: Balhannah Nurseries 2016)

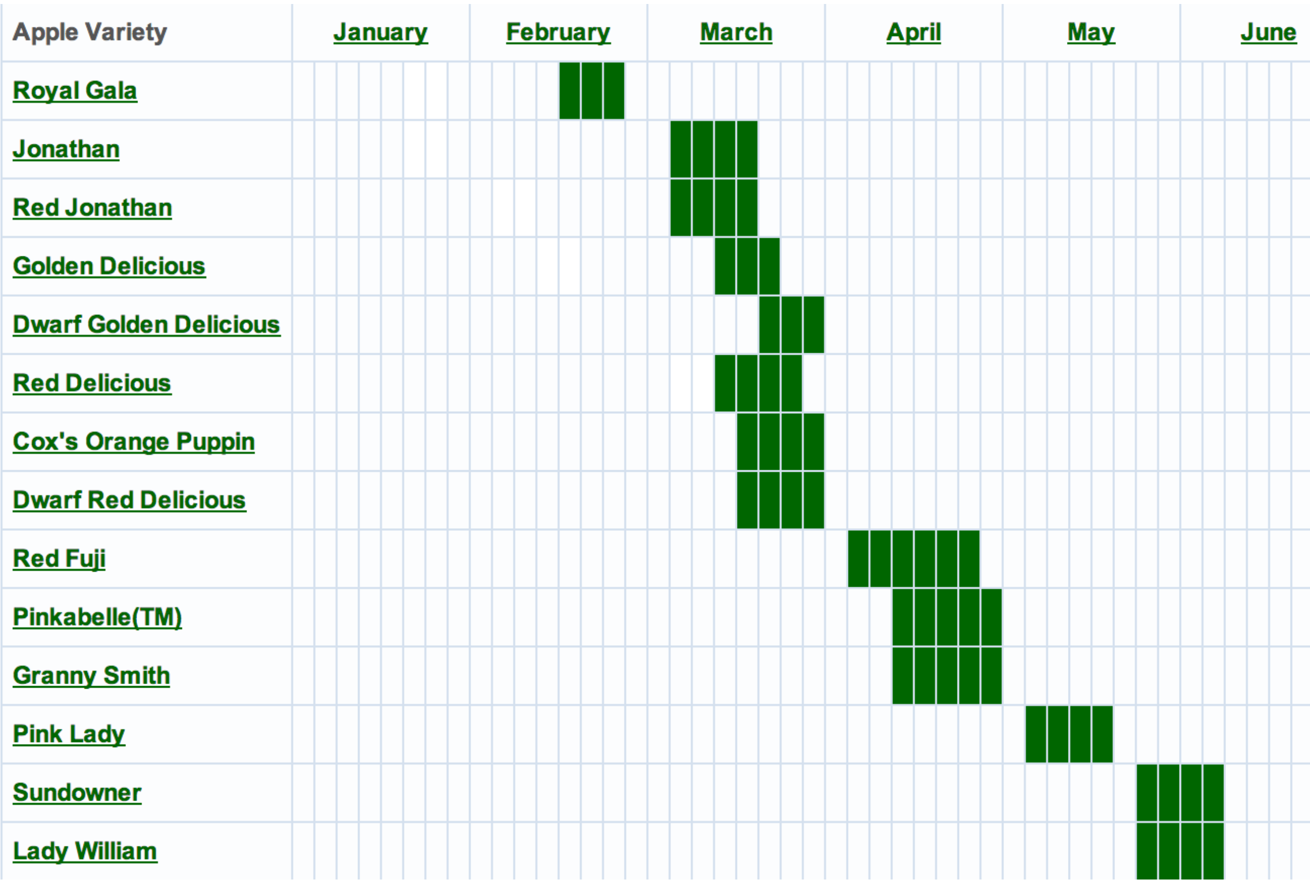
A. Stone Fruit

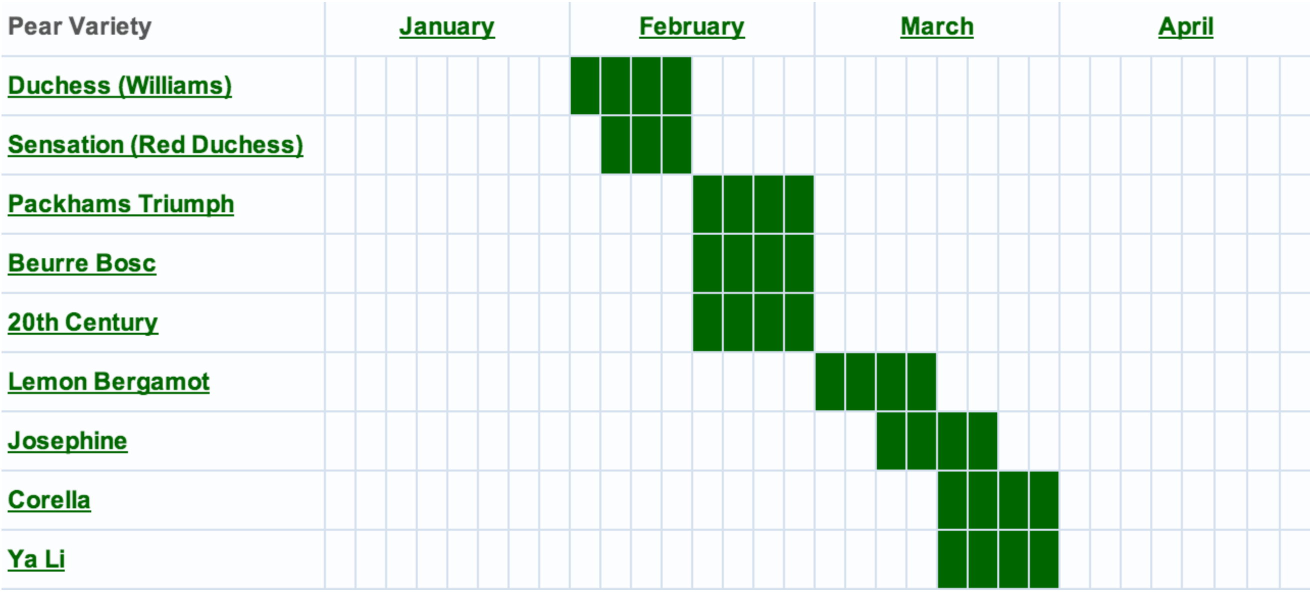

Nectarine Variety
November
December
January
February
March
Cardinal
Firebrite
Dwarf Nectarine
Peacharine
Flavortop
Fantasia
Goldmine
New Boy
Sunset Nectarine(TM)
Fairlane


Cherry Variety
November
December
January
Burgsdorf
Vista
Rons Seedling
Napoleon
Van
Sunburst
Stella
Bing
Black Boy
Morella
Williams Favourite
Lapins


Plum Variety
December
January
February
March
April
Santa Rosa
Queen Rosa
Wickson
Angelina Burdett
Mariposa
Stirling
Satsuma
Coes Golden Drop
Green Gage
Narrabeen
President
Ruby Blood

B. Pome fruit


Apple Variety
January
February
March
April
May
June
Royal Gala
Jonathan
Red Jonathan
Golden Delicious
Dwarf Golden Delicious
Red Delicious
Cox's Orange Puppin
Dwarf Red Delicious
Red Fuji
Pinkabelle(TM)
Granny Smith
Pink Lady
Sundowner
Lady William


Pear Variety
January
February
March
April
Duchess (Williams)
Sensation (Red Duchess)
Packhams Triumph
Beurre Bosc
20th Century
Lemon Bergamot
Josephine
Corella
Ya Li