

MURR-2024-022 RISK PROJECT REPORT

‘Risk Management (Climate Change) for Plantation Establishment in the Murray Region Forestry Hub (MRFH)’

This report was commissioned by the Murray Region Forestry Hub with funding from the Australian Government, Department of Agriculture, Fisheries and Forestry.



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1. SUMMARY

The purpose of this report is to document the potential future impacts of **climate change** on the optimal areas for re-establishment of softwood plantations in the Murray Region Forestry Hub area, following the devastating bushfires of 2019/2010. In particular, the study examines the areas most suitable for establishment of new plantations under various climate scenarios. Ensuring that plantations are established in the most appropriate areas requires the identification of (and mitigation against) numerous **risk factors** that need to be considered when determining the optimal location and management of plantations in the future.

Apart from climate change, the other risk factors that were originally identified for further studies included:

- Product Demand Developments and Changes
- Land Capability Assessments
- Land Availability
- The Influence of Factors Affecting Plantation Viability
- Productivity Impacts
- Carbon Opportunities and Influences

Ultimately, these risk factors are all inter-linked, however, examining them separately would help ensure the key issues and potential solutions are adequately reviewed and prioritised. The decision as to which of the projects might be progressed and when, will be determined by the MRFH Steering Committee.

This report looks specifically at how climate change may influence the location, scale, composition, and management of existing and future plantations in this region. The background information for this report was compiled by Spatial Vision and has also been reviewed by grower representatives from the MRFH.

Key Outcomes:

- Even under the more extreme climate-change scenarios, the MRFH area will still have large, climatically suitable areas that will support the growing of *Pinus radiata* in large scale plantations.
- It is apparent that a changing climate will add another overlay to the suite of considerations when either re-establishing existing plantation sites or establishing new sites. It will also present some operational challenges and require flexibility and adaptation when considering silvicultural and protection measures for the plantation estate.
- This work has identified some other questions and issues that are worth considering for the future.
 - How could the data and information developed by this report best be utilised by the industry?

- Should the industry adopt a state or national approach to this issue or is it best considered at a more local level?
- What further data analysis would be helpful?
- How might data be used in more formal, risk management assessments?
- Is there a role for the Hubs to undertake similar assessments at a joint level?

2. INTRODUCTION

The bushfires of 2019/2020 burnt around 50,000 ha of established softwood plantations within the area covered by the Murray Region Forestry Hub (MRFH). In considering options for plantation re-establishment, the need to identify the risks posed by possible climate changes (amongst other challenges) was recognised. This project was undertaken to explore the likely dimensions of possible future climate scenarios and to understand the impacts that such changes might have on the potential productivity of softwood plantations in the MRFH footprint.

It was also recognised that the estate will need to be expanded to meet future wood demands. Where this expansion could potentially take place and how that expanded area might interact with other land-uses was also considered. This aspect provides a challenging interface between the climate change issues and Land Capability study that has also been completed by the MRFH.

Various climatic forecasting models have suggested that Australia's climate could become more variable. This impact could be seen as a potential opportunity and/or threat to the viability of Australia's plantations. Changes in climatic variables such as temperature and rainfall may require changes in management or location of plantations to capitalise on opportunities and reduce the potential threats.

As an example of other general work on plantation viability and climate change, the FWPA Study referred to in this report is summarised in Appendix 1.

3. OTHER RISK FACTORS

Apart from climate change, other risk factors are currently subject to specific review & analysis outside this report. Table 1 shows the 7 elements of Risk Management that may be explored further by the Hub.

Ultimately, these risk factors are all inter-linked, however, examining them separately will ensure the key issues and potential solutions are adequately reviewed and prioritised. It will also optimise the way possible policy options can be developed.

Table 1.

No.	Issue/Requirement	Output
1	Climate Change Mapping	Climate based map with essential parameters now & forecast for the future; annual outputs plus seasonal/intra seasonal variation potentials
2	Product Demand	Estimates of future log availability & general product demand
3	Operational Mapping	In addition to item 1. Land capability for plantation establishment; current plantation areas; existing land uses; soil types
4	Impacts on tree growth rates	Productivity impacts (ie effects on MAI); Options for changes to silvicultural practices to optimise productivity & satisfy market requirements
5	Land Quality assessment criteria	What are objective parameters to best assess land suitable for plantation establishment. What scenarios could apply (mix & match) to obtain best-use options?
6	Plantation-Land Possibilities	Desk top analysis to re-review all the lease/tenancy; rental & purchase options that have been looked at previously; determine approaches with most appropriate application at a local level
7	Carbon Pricing Opportunities/Developments	Current state of play for carbon initiatives & likely impacts on the economic analyses for plantation developments

4. CLIMATE CHANGE IMPACTS – The MRFH Model

To understand the possible impacts of climate change specifically on the MRFH region, a report was commissioned from a specialist Geographic Information System (GIS) and modelling consultant, *Spatial Vision*. The purpose of this element within the overall Risk Management project was to identify those areas within the Hub boundary where plantations are likely to be significantly impacted by anticipated climate change, such as increased surface temperatures, drought, rainfall, and changes in the seasonality of rainfall and temperature.

This report was essentially a mapping exercise and produced a series of climate related views of the region showing the current and projected futures. The presentation of recent observation information was also prepared to provide an improved understanding of the changes that have already been experienced in recent decades.

4.1. Modelling Background - General

The most recent climate modelling prepared by CSIRO as an outcome to the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (AR5) was accessed by Spatial Vision. To model and project climate change at a national or global scale, various organisations world-wide have created a suite of General Circulation Models (GCM) to assess the likely changes in climate using different variables. Further to the base GCMs that are available for use, there are various scenarios explored within a GCM. This is done by establishing an emissions pathway that looks at worldwide responses to greenhouse gases and other pollutants. These are grouped and modelled under Representative Concentration Pathway (RCP) emissions scenarios. A non-fossil fuel future (RCP 2.6) through to a fossil fuel intensive future (RCP 8.5) and other options in between, can be explored, analysed and applied to plantation development scenarios.

4.2. The MRFH Model

A resolution of 5km² over the MRFH has been obtained within the suite of projections initially made available in 2015. These have been updated based on new understandings and Climate Data. (Climate Data – SWS May 2021, Spatial Vision)

Modelled changes in the climate can be expressed in terms of climatic variables. The 12 variables used for the MRFH Region are:

- i. Mean Daily Maximum Temperature (Temp Max)
- ii. Mean Daily Minimum Temperature (Temp Min)
- iii. Days with Temp Max greater than 40C – very hot days
- iv. Days with Temp Max greater than 35C – hot days
- v. Top 1% of Events - Daily Max Temp for month across period
- vi. Days with Temp Min less than 2C – frost days
- vii. Days with Temp Min less than 0C – very cold days
- viii. Three or more consecutive days with Temp Max greater than 35C – Heatwaves

- ix. Days with Temp Max greater than 35C and Temp Min greater than 20C – Heat stress days
- x. Total Precipitation (mm) for period
- xi. Days with Daily Rainfall greater than 10mm
- xii. Top 1% of events – rainfall for month across period

Spatial views of where change is likely to occur, such as which areas are more likely to be subjected to a greater number of heatwaves, are required to identify the likely impact of the anticipated changes.

The models (and RCP) used in this study are:

a) **ACCESS 1.0 - CSIRO and BoM**

Representing a maximum consensus future based solely on model agreement. It represents the category with the greatest number of models that agree. The ACCESS model does not deliver such extreme forecasts of climate and can be interpreted as an average of alternatives.

b) **HadGEM2-CC - Met Office Hadley Centre**

The Had GEM model represents the group of models identified as predicting the hottest and driest climatic conditions. This model was selected as it provided a more extreme, or dire, prediction of the future climate.

c) **Two Recommended Concentration Pathways (RCP) emissions scenarios**

- RCP 4.5 - ideal scenario of curtailing changes to warming less than 1.5°C.
- RCP 8.5 - conservative, high emissions 'business as usual' scenario.

d) **Future time points:** 2030 2050 2070 2090

- Represented as absolute values or change from a baseline period.
- Baseline is typically the average of observations from 1981 to 2010.

The study also drew on historical observations. Historical climate observation data can be a useful source of knowledge to help understand what has occurred in the past. Historical climate data was obtained from weather observations sourced from the SILO Project (Scientific Information for Land Owners) which is a database of Australian climate data from 1889 to the present. (Also see: <https://www.longpaddock.qld.gov.au/silo/>). It utilises Bureau of Meteorology weather data which is then modelled into a continuous gridded surface. This is presented at a 5km² resolution, like the future projected climate scenarios. The historical climate observation data shows that since 1970, the average daily maximum and minimum temperatures have increased, with the last decade (2010 to 2019) being the warmest. This warming is also expressed in terms of an increase in the number of days greater than 35°C and 40°C, as well as other variables.

Using these modelling techniques, over the entire MRFH area, up to six GCMs (General circulation models which are mathematical models capable of representing physical processes of the atmosphere and ocean to simulate response of global climate to the increasing greenhouse gas

emissions. IPCC, 2013) for the projected years of 2030, 2050, 2070 and 2090 are available at two RCP emissions scenarios of 4.5 and 8.5. These six models can provide a range of projected climate changes and impact assessments ranging from a warmer and minimal rainfall change to a hotter and drier future.

It should be noted that of the eight scenarios modelled, none are more likely to occur than another. Each future model projection is as likely as the other. However, each scenario can be suited to expressing a particular change more so than another, or they can be more suited for a particular region.

For the MRFH region, two models were used – ACCESS and HadGEM. These two models have been applied for this project to demonstrate potential changes from a current baseline. For forestry operations, rainfall deficiencies are a key variable that has a significant impact on the suitability and productivity of existing and future plantations. Hence, a forecast drier future can help explore the extreme changes that may occur under the worst likely climate projections.

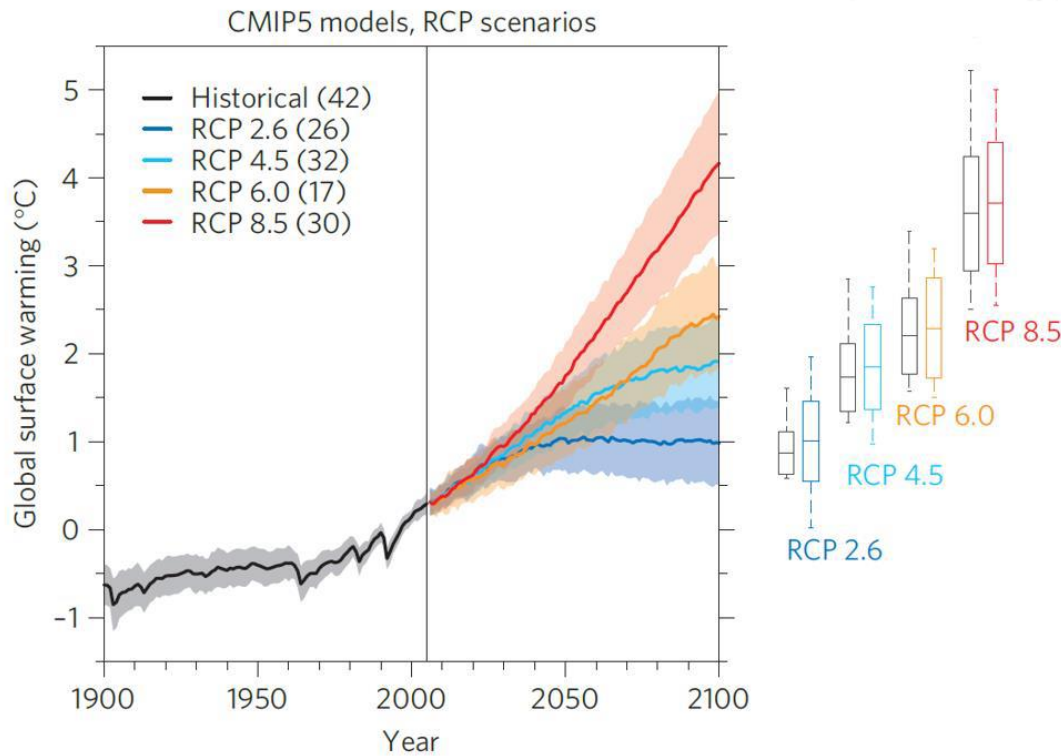
The projection data uses baseline climate information from the period 1981 to 2010. Any changes can be made by assessing the difference between the current time and any future projections. These two models were run at both RCP scenarios which ranges from an ideal scenario where warming changes are restricted to less than 1.5°C (RCP 4.5) through to a high-emissions, 'business as usual' scenario (RCP 8.5). Projections were then applied for the years 2030, 2050, 2070 and 2090 to evaluate the likely climate futures at these times.

The estimated climate parameters for these years were based on the average of modelled climate parameters (such as maximum daily temperatures) for the following periods:

- 2030 – based on average for period 2016 to 2045
- 2050 – based on average for period 2036 to 2065
- 2070 – based on average for period 2056 to 2085
- 2090 – based on average for period 2076 to 2106

It is noted that for the period to 2030, changes in the projections between any GCM at both RCP 4.5 and 8.5 may be minimal, but periods after will have larger differences (see Figure 1).

Figure 1. Relationship between four new scenarios, denoted Representative Concentration Pathways (RCPs), where RCPs provide standardised greenhouse gas concentration inputs for running climate models.



5. RESULTS AND DISCUSSION

The **results** from this modelling exercise indicate that:

- i. There is an extensive amount of data that can be provided. However, to provide a *general* indicator of land suitable for plantation establishment, rainfall predictions are considered the most insightful and useful, single risk-indicator for the MRFH region. This measure has been a driver of drought mortality in the region historically.
- ii. Historical decade by decade rainfall levels are relatively consistent across the MRFH area apart from 2000-2009. This period is commonly referred to as the *Millennial Drought*. Significant tree mortality occurred in vulnerable stands during this period and represents an 'indicator' of potential future risk.
- iii. Long term models would represent an 'average'. As expected, there will be both good and bad years in the future, but there will be a higher proportion of 'bad' years.

- iv. RCP 4.5 average is not as severe as 2000-09, but RCP 8.5 is significantly worse. Anything within the range of these two potential outcomes is worse than current average, with a higher probability of the 2000-09 events re-occurring.

The **implications** for new plantations or re-establishment of existing plantation areas that can be drawn from this modelling are:

- a) New plantations would need to be established in more easterly, higher rainfall zones to mitigate climate risk. At the macro level, land in these higher rainfall zones can be expected to be more expensive as it would also represent the ideal location for other high value agricultural and horticultural activities. However, it is possible that within these areas, certain parcels of land may be suitable for more traditional farm-forestry projects where smaller commercial wood lots are established in conjunction with 'traditional' agricultural activities.
- b) The existing plantation footprint would have larger areas exposed to higher mortality risk. Some areas may become economically/biologically unviable. There would be increased risks:
 - i. at establishment resulting in poor survival
 - ii. in pre-commercial condition, post canopy-closure

Other related impacts of these forecast climate scenarios include:

- a. **Drought**
Stand structure at a time of drought influences risk and unthinned stands older than 7-8 years are most susceptible. Thinning does appear to reduce the mortality risk.
- b. **Aspect**
Northern and western aspects and exposed ridges have higher risk.
- c. **Slope**
Lower slope/riparian zones can be satisfactory with reasonable tree survival rates.
- d. **Soil types**
Ex-pasture sites appear more prone to tree-mortality. The risk on Carabost shales is lower than northern Green Hills/northern Buccleuch soils, i.e. soils/soil water holding capacity does influence risk.
- e. **Sun period**
Evidence of 'sunburn' and/or dead sides on exposed north facing stems on sites prone to higher mortality rates.
- f. **Species selection**
Trials of *P. pinaster* have not demonstrated it would be a reliable alternative to radiata pine for timber production. While mortality risk is reduced it has still

occurred on Joint Ventures (JVs) west of Hume Hwy. Growth/productivity is very low compared to *P. radiata*.

It should be noted that, historically, commercial pine plantation establishment of any species west of the Hume Highway and adjacent to the MRFH boundary, has never been successful over a full rotation.

g. Site variability

Potential to establish plantations on the lower-value parts of the farming landscapes and manage higher-value areas for other agricultural/horticultural activities.

h. Silvicultural adjustments/opportunities

i. Planting density.

Higher stems/ha regimes will become an 'at risk' stand earlier and potentially be exposed to risk for longer. Lower stems/ha regimes reduce mortality but could impact wood quality for routine sawlog regimes.

ii. Thinning age and frequency.

Early age thinning can reduce mortality risk in vulnerable stands.

iii. Productivity.

Impacts are unclear, with some indication that elevated CO₂ generates more growth but counterbalanced by drought risk/mortality.

iv. Rotation length.

Flexibility would be advantageous, requiring liaison with customers/contractors to be able to respond to climate events that require changes to scheduling and sales arrangements. Drought prone areas may not be able to grow through to a conventional clear-fall regime with acceptable risk.

v. Elevated fire risk.

Significant plantation fire losses correlated with extended and prolonged dry periods.

7. OTHER INTERPRETATIONS OF THE MRFH MODELLING EXERCISE

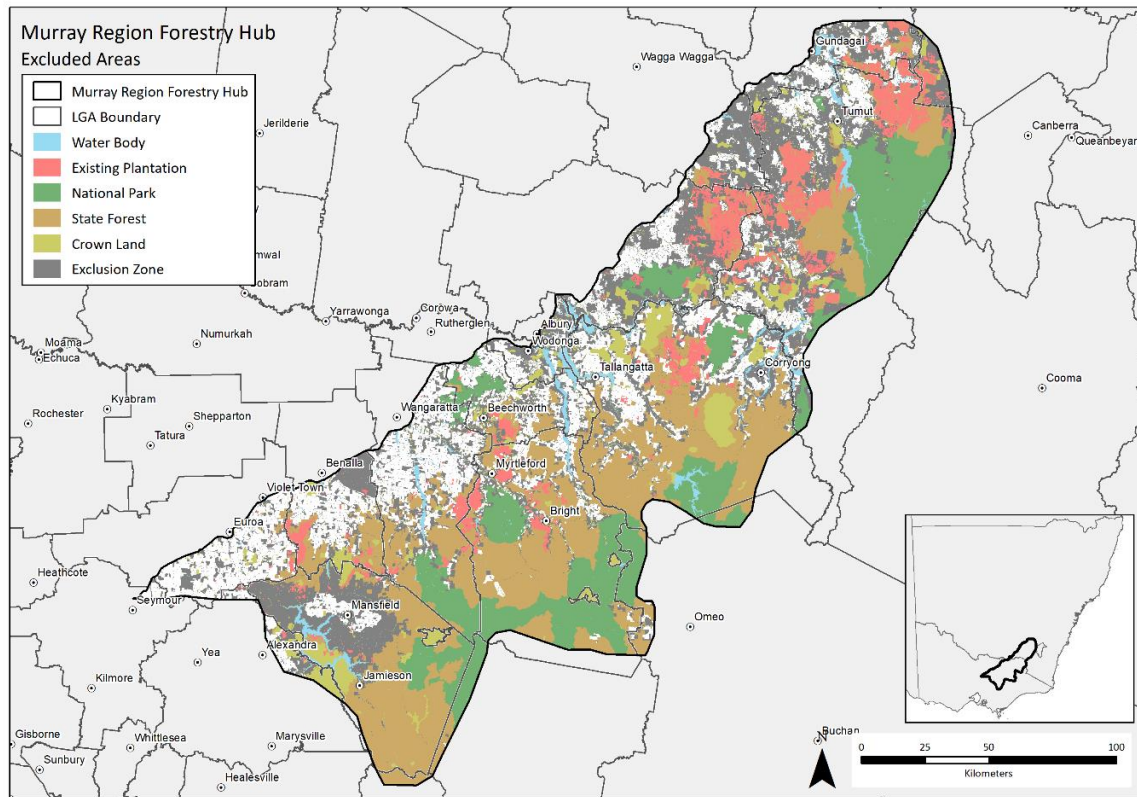
The HadGEM model with an RCP of 8.5 has been used as a more dramatic or extreme case study to demonstrate the potential changes that might occur to plantation-land suitability over the next 60 years as result of climate change.

This can be compared with the outcomes of the separate 'Land Suitability' project that was undertaken by PF Olsen (July 2023). That study generated outcomes that were more 'middle of the road' and improved the outlook for plantation development in this region markedly.

According to the Olsen report, the Murray Region Forestry Hub has just under 185,000 hectares of highly suitable land that could be developed for future radiata pine plantations. Under two climate scenarios, an 'intermediate' scenario would see the highly suitable land decrease from 185,000

hectares to less than 80,000 hectares by 2090, and the ‘worst-case’ scenario would see a significant reduction by 2090 to below 30,000 hectares.

Figure 2: Map showing existing land use and excluded areas within the MRFH boundary.



From Plantation Land Suitability Analysis (MRFH) by PF Olsen Oct 2023

The following excerpts and results from the PF Olsen Report also examined the potential climate change impacts.

Note that the Suitability Classes depicted in the following charts range from 1 being the poorest through to 5 being the most ideal sites.

Area (ha) of suitable land by State and suitability class - current climate

Class	New South Wales	Victoria	Total
1	131	5,797	5,928
2	85,620	131,932	217,552
3	90,253	216,562	306,815
4	15,537	130,287	145,824
5	19,393	19,672	39,065
Total	210,934	504,250	715,184

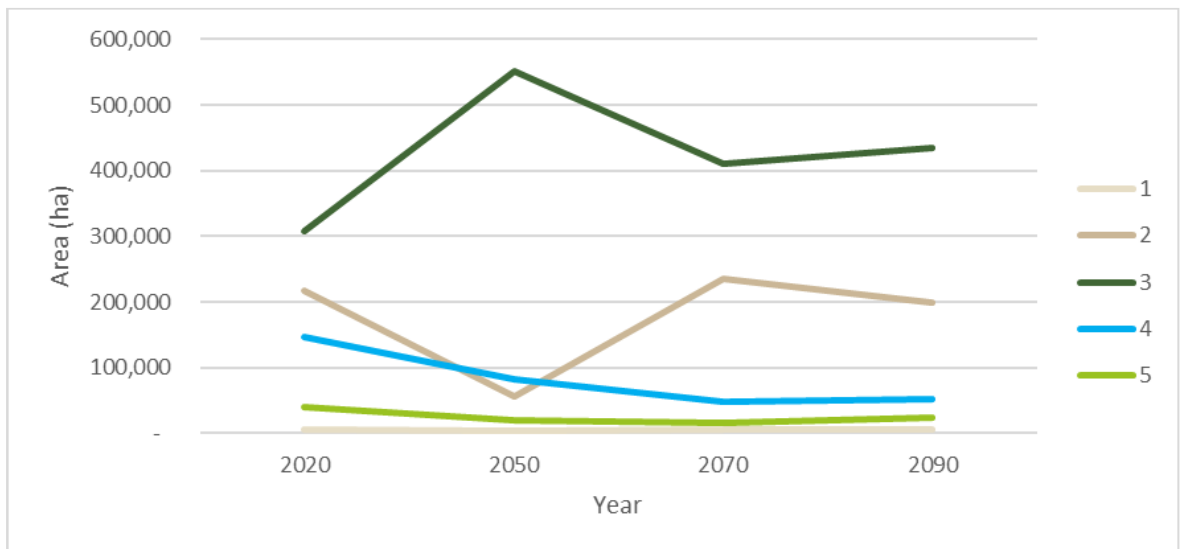
Two future emission scenarios, called Representative Concentration Pathways (RCP) have been used; RCP 4.5 and RCP 8.5. The 4.5 scenario is an intermediate emissions scenario where emissions peak in 2040 then decline thereafter. This is considered a more probable

emissions pathway. The 8.5 scenario is where emissions continue to rise throughout the 21st century and is considered a worst-case scenario.

One GCM model has been used for this project, ACCESS 1.0, which was created by the CSIRO and the Bureau of Meteorology. This is considered a middle range model in that it is not an extremely hot/dry GCM or a warm/wet GCM.

Figure A presents the change in area within each of the suitability classes starting from the current climate (2020) and projected forward with the 'intermediate' climate scenario (RCP 4.5). For this scenario, we can see that there is a decrease in area for the two most suitable classes (4 and 5) through the time projections. There is a reduction in area for Class 2, and a corresponding increase in area for Class 3 between the current climate and the projected 2050 climate. This increase in suitability is most likely due to a reduction in the number of frost days within the Hub region, the areas then mostly revert back, and this is likely to be influenced by the reduction in annual rainfall.

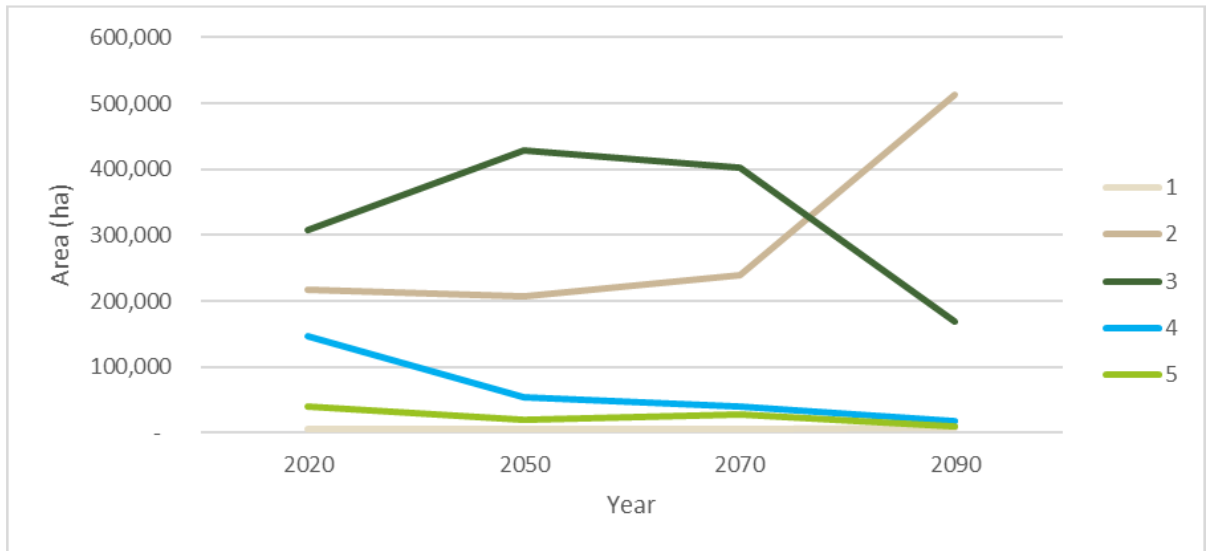
Figure A - Area by suitability class and projected climate based on RCP 4.5



Note that the Suitability Classes depicted in this chart range from 1 being the poorest through to 5 being the most ideal sites.

There are some similarities between the intermediate scenario and the 'worst-case' scenario (Figure B). In this climate scenario, there is also a more significant decline in area of the two most suitable classes. There is a less pronounced increase in Class 3 area from the current climate to 2050, and a significant drop in area by 2090.

Figure B - Area by suitability class and projected climate based on RCP 8.5



Note that the Suitability Classes depicted in this chart range from 1 being the poorest through to 5 being the most ideal sites.

The modelling work undertaken by Spatial Vision has provided historical rainfall records as well as forecasts through to 2090. The rainfall metric has been provided as both a monthly graph (Figs C and D) and decadal bar charts (Figs E and F).

The HadGEM climate model has also been used to provide a more extreme outlook on climate change within the period. Some outputs and brief commentary from that modelling have been provided in the next section of this report.

Figure C: Historic Monthly Rainfall Graph

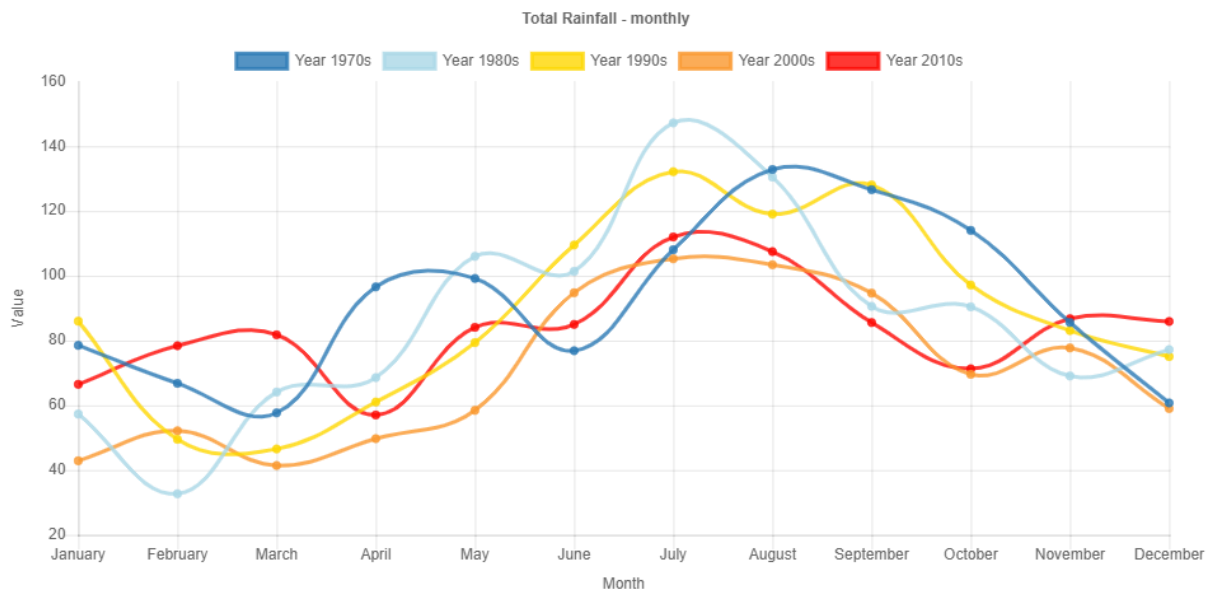


Figure D: Forecast Monthly Rainfall Graph

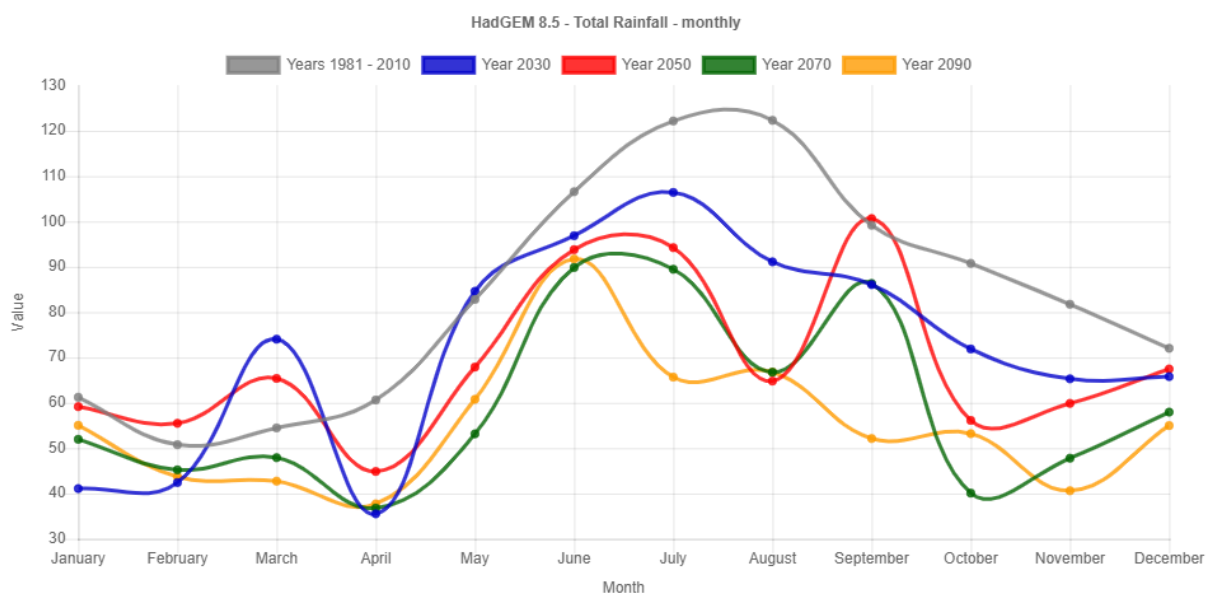


Figure E: Historic Rainfall Chart by Decade

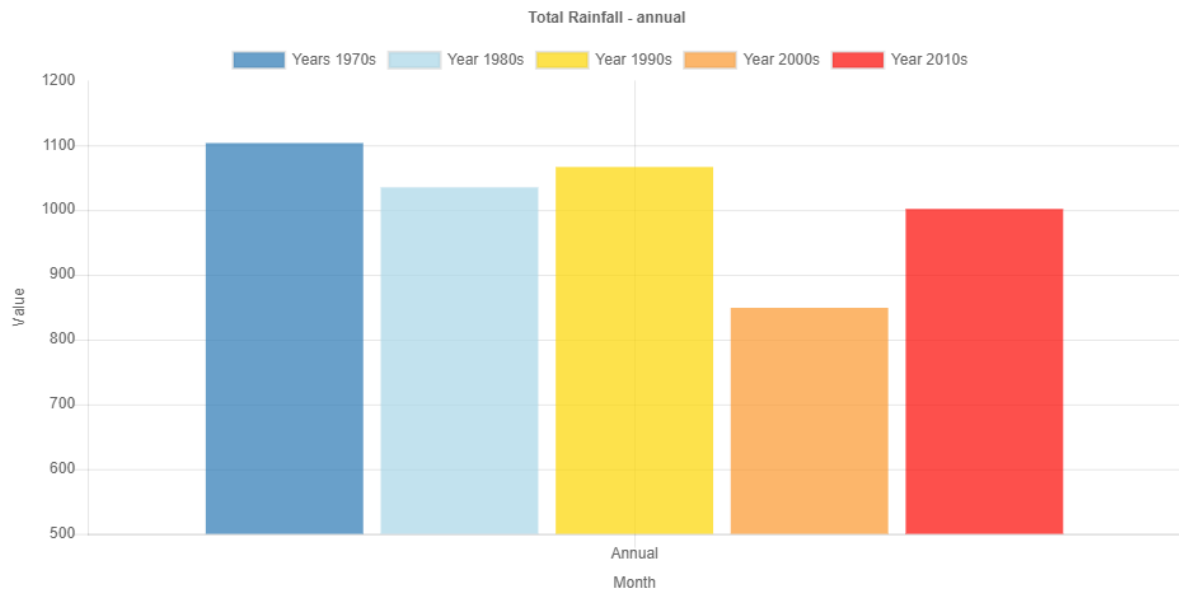
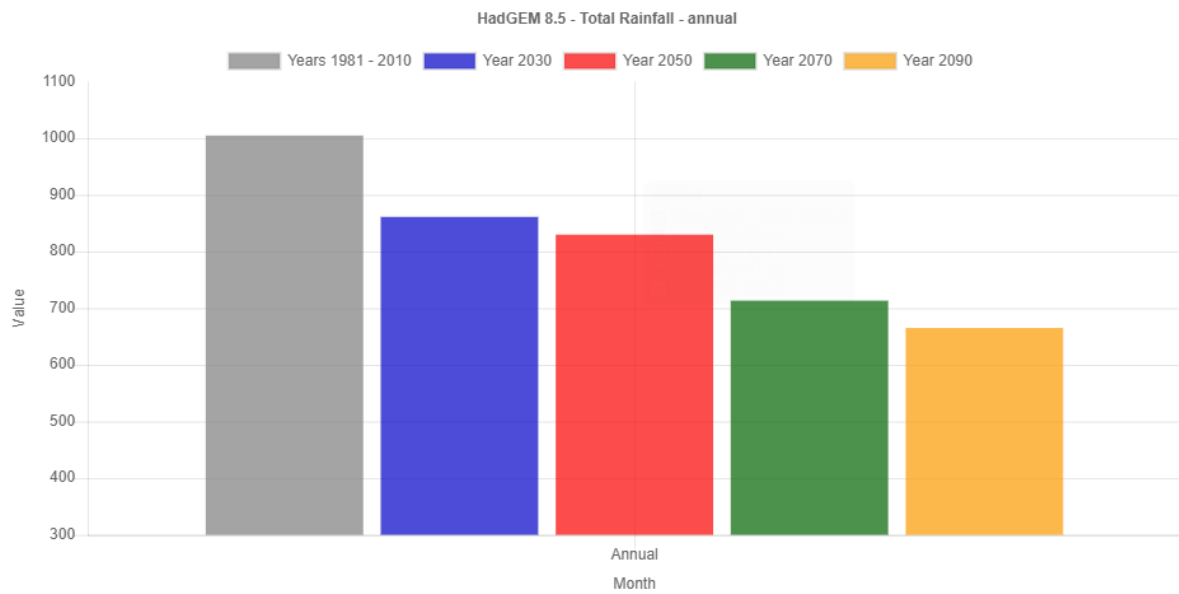


Figure F: Forecast Rainfall Chart by Decade



The following pages show the potential movement of the 600mm rainfall isohyet (red line) under the most extreme climate-model scenario for the decades, 2030, 2050, 2070 and 2090 under the HadGEM RCP 8.5 scenario. (Figures G, H, I, J)

It is important to recognise that this demonstration of the 'movement' of this isohyet to the southeast is considered an extreme position. The less pessimistic models still indicate some similar patterns; however, the amount of movement is considerably less.

Ultimately the outcome indicates that this region is still ideally suited to support a sustainable and viable forestry plantation industry that is deserving of further expansion and development in the growing and processing sectors. It will continue to have its challenges that climate change will undoubtedly underpin; however, these can be addressed with more adaptive and concerted management efforts at an operational level.

In addition to this, we now have the tools available at a local (ie Hub-based) level, to undertake even further investigations that will facilitate more constructive and informed scenario modelling and plantation establishment planning..

Conclusion:

Climate change (CC) will have both positive and negative impacts on the plantation sector within the MRFH and is one of many risk factors that need to be considered for new and re-established plantations.

Despite the potential future impacts of CC, the region appears well placed to continue to develop and expand the softwood plantation estate. To do this will require additional focus on climate related issues with management practices adjusted or changed to suit the prevailing and expected circumstances. Fire risks are of particular concern.

It is also clear that the Government support programs designed to encourage and assist plantation expansion and processing operations in the MRFH are appropriate and justified as is the support for further Research and Development activities.

Fig G. HadGEM RCP 8.5 -2030 Total Annual Rainfall Forecast

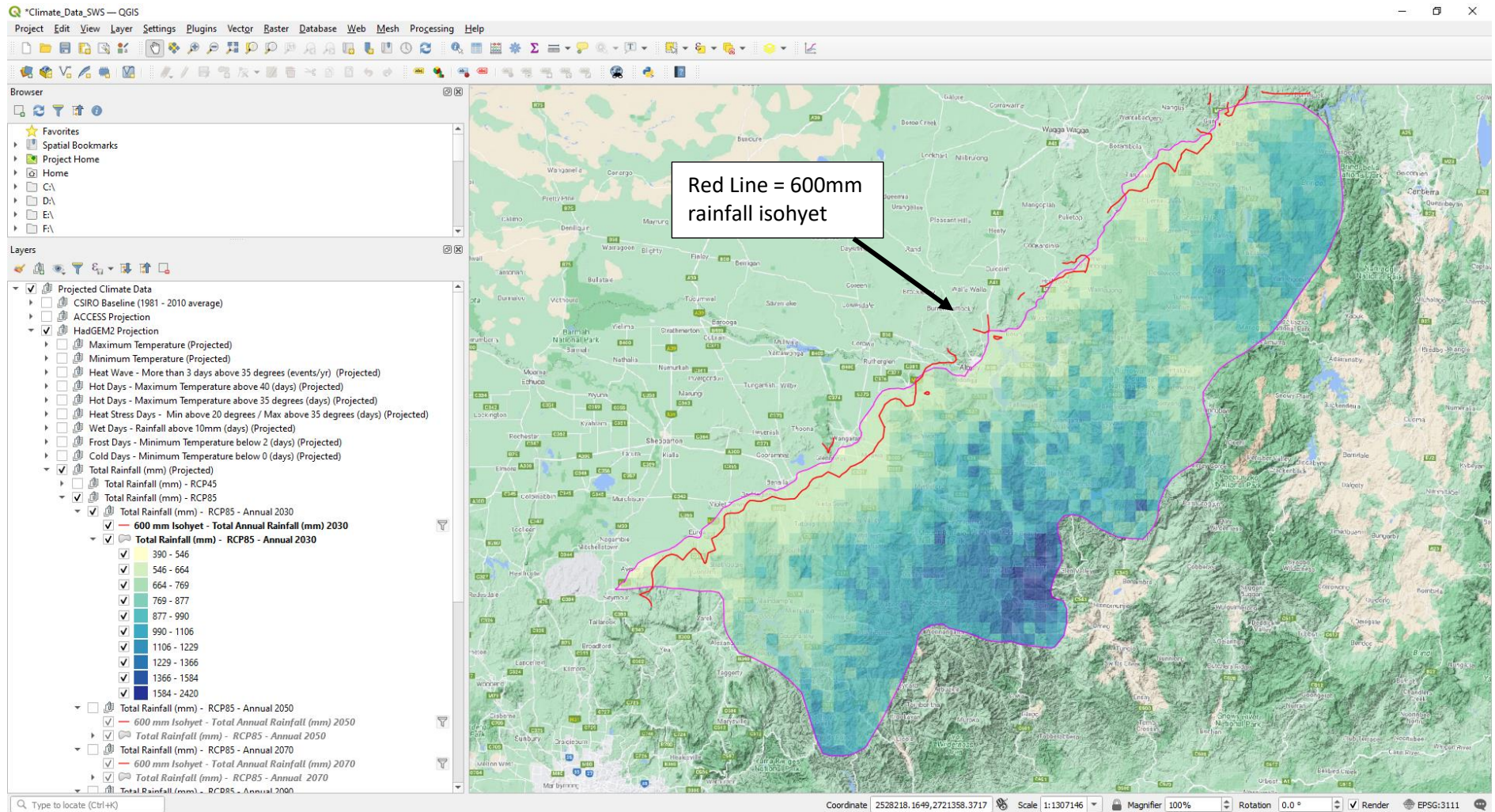


Fig. H. HadGEM RCP 8.5 -2050 Total Annual Rainfall Forecast

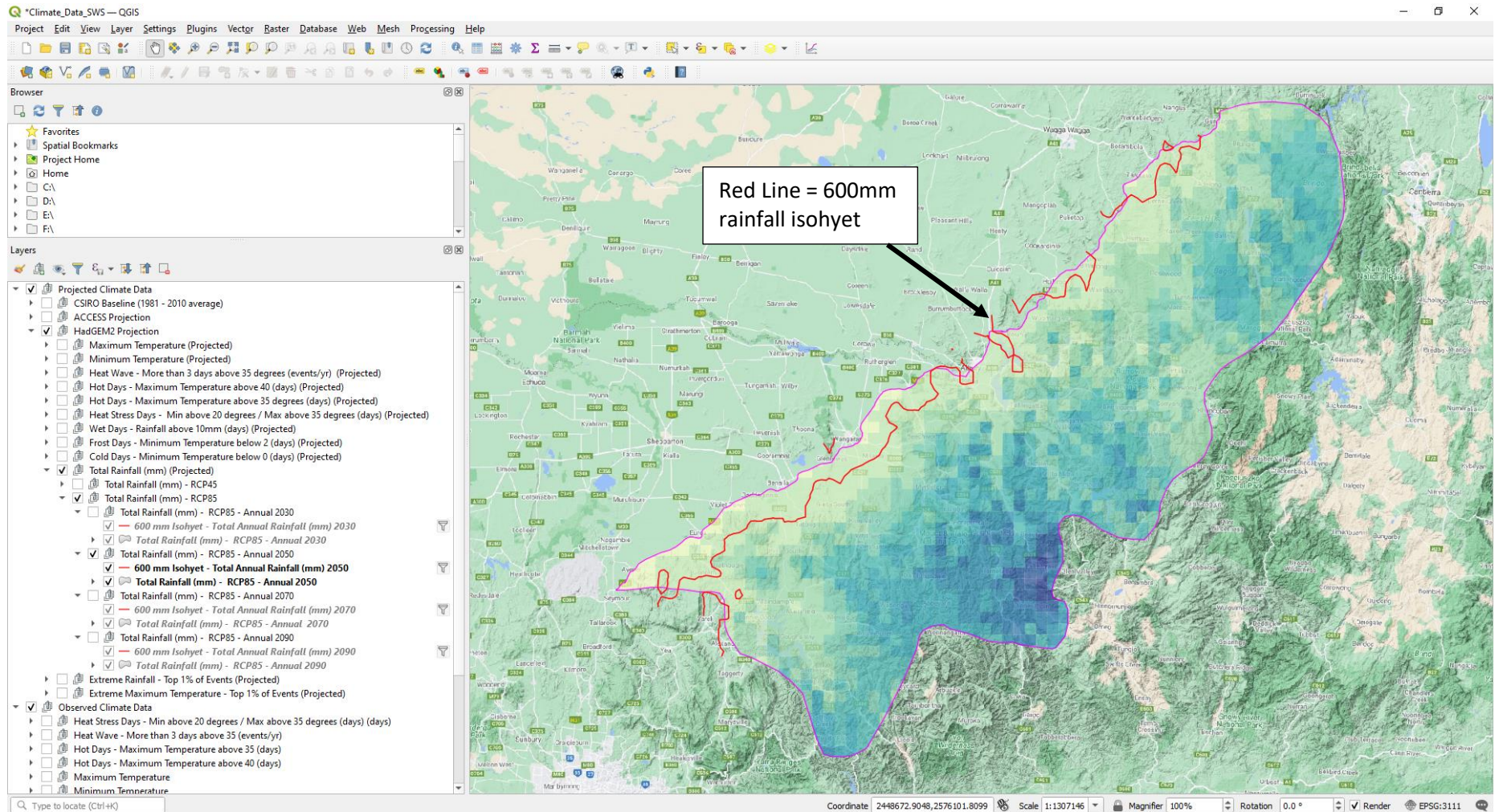


Fig I. HadGEM RCP 8.5 -2070 Total Annual Rainfall Forecast

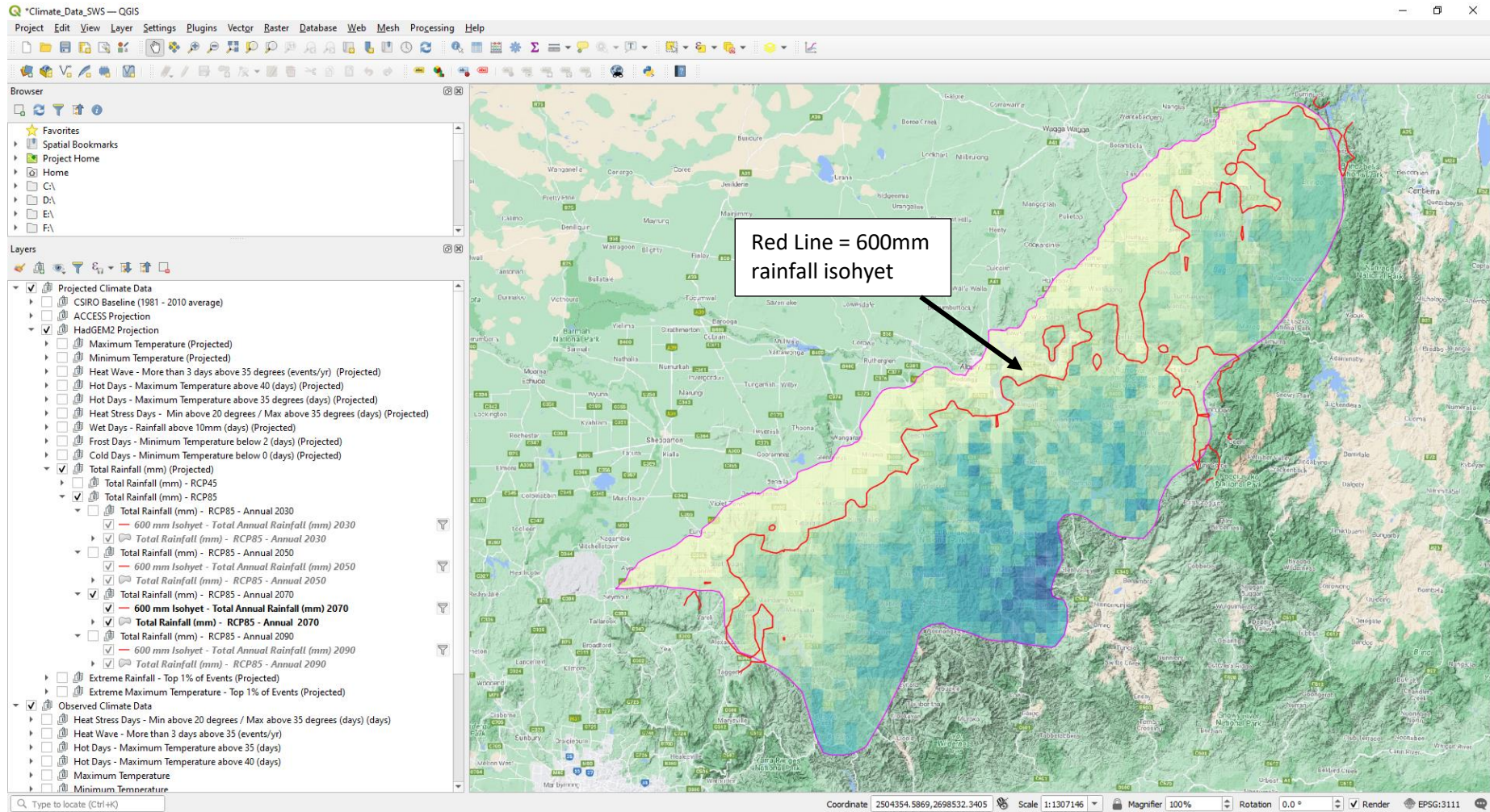
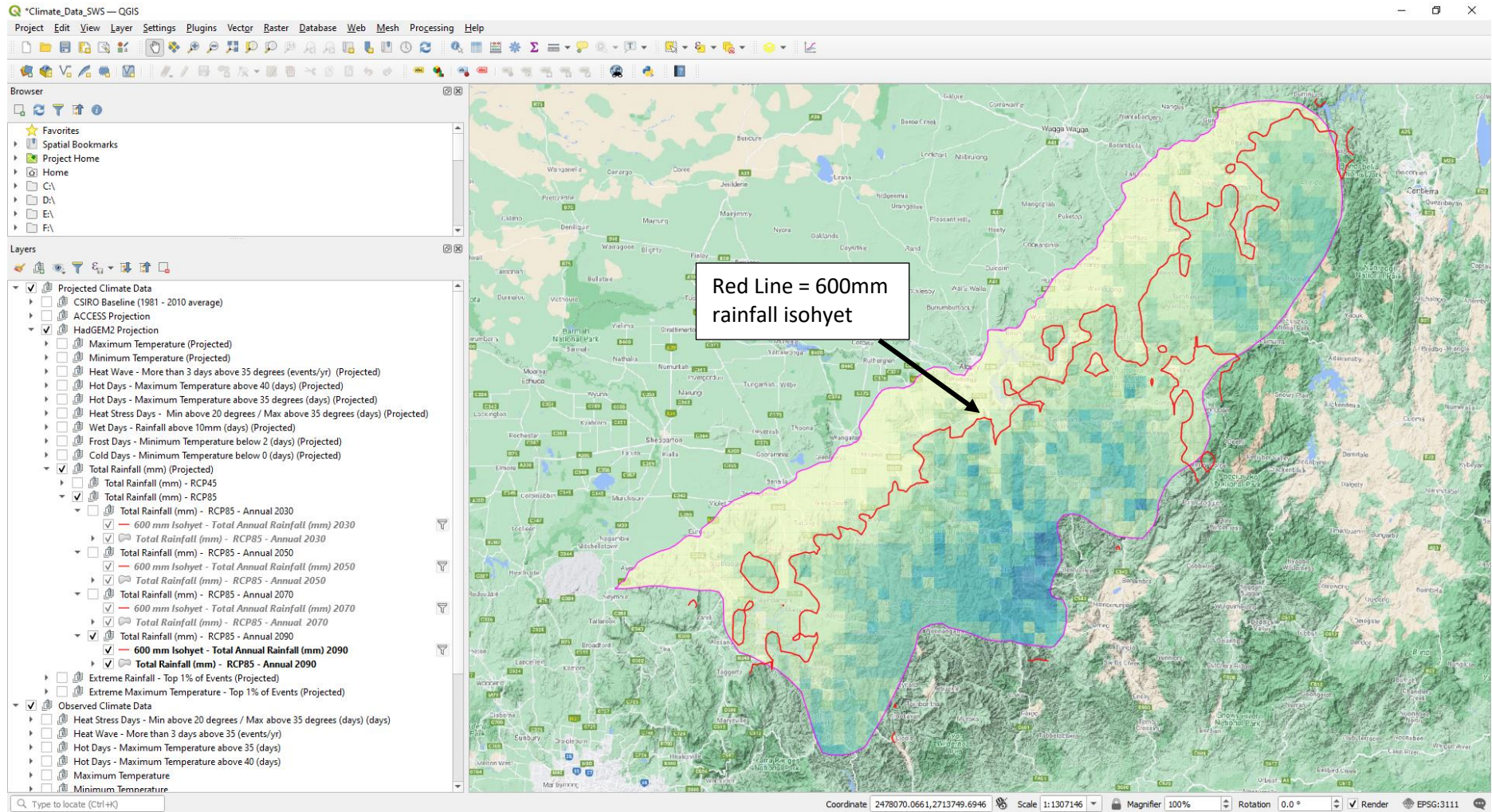


Fig J. HadGEM RCP 8.5 -2090 Total Annual Rainfall Forecast



8. REFERENCES

1. FWPA Climate change and Australia's plantations (REGIONAL REPORT 6: Victoria and southern New South Wales Radiata pine plantations). CSIRO published 2014.
2. Spatial Vision SWS Forestry Hub Risk Management Project 17/12/20 Climate Data
3. From Climate Change and Australia's plantation estate: Analysis of vulnerability and preliminary investigation of adaptation options Prepared for Forest & Wood Products Australia by M. Battaglia, J. Bruce, C. Brack and T. Baker Oct 2009
4. MRFH Plantation Land Suitability Analysis. PF Olsen July 2023

Appendix 1.

The FWPA (CSIRO Model) Study – A Summary.

The bulk of Australia's pine plantations are in cool temperate southwestern and southeastern Australia. A study prepared by FWPA (Climate change and Australia's plantations REGIONAL REPORT 6: Victoria and southern New South Wales Radiata pine plantations) summarises the possible consequences of a more variable climate for softwood plantations in eastern and central Victoria and southern NSW pine plantations by 2030. These consequences are described in terms of:

- stand productivity and wood properties,
- the likelihood of stand failure due to drought and implications of this for final stems per hectare,
- risks from fire
- risks and impacts of pests.

The report also presents possible adaptation strategies to reduce negative impacts of climate change on plantation productivity.

The Climate Futures Framework (Whetton et al 2012) was used by the FWPA study to select climate models that represented the worst case, most likely and best-case climate futures for the main temperate plantation regions in Australia, resulting in 4 – 5 climate models being run per region. Data was used to reflect anticipated climatic conditions in 2030, 2050, 2070 and 2090. (ie. Essentially two 'normal' *P.radiata* rotations)

Impacts on Plantation Productivity

In the FWPA study, productivity estimates were updated from previous analyses, using the process-based model, CABALA (**CArbon BALAnce**; A linked carbon, water and nitrogen model of forest growth for silvicultural decision support).

Six standard soil types were set up (low, medium and high fertility for each of shallow and deep soil depth) to provide broad representation of soils in each plantation region. The silvicultural regime was a 35-year rotation planted at 1300 stems/ha (sph), an at-planting fertiliser application and thinning at ages 11 (to 750 sph), 19 (to 450 sph) and 26 (to 250 sph). Twenty separate rotations were simulated by running the model with 20 different planting dates over a 30-year period of weather. For each region, simulations included the factorial combination of 6 soils, 5 climate models, 3 time frames and 20 planting dates. The number of surviving rotations out of 20 was calculated to estimate probability of plantation failure. The coefficient of variation provided a measure of inherent variability in the region. For all combinations, the model was run assuming either no acclimation or full acclimation of photosynthesis to higher atmospheric CO₂ concentration, reflecting the high uncertainty around how plantations will respond to higher CO₂.

a. Production.

Where there is no response to elevated CO₂, production is predicted to range from losses up to 25% to positive responses of 25%. The southern parts of the estate are generally predicted to remain similar under the median scenario with decreases of up to 25% in the least favourable scenario. These areas are amongst the more productive parts of the region. The colder areas around the Australian Alps are likely to see increases in production as the temperature limitations are reduced. In regions where productivity is predicted to decrease (less than 25% loss), adaption through changes in silviculture may mitigate the potential losses in production. Where there is predicted response to elevated CO₂, production is positive across both deep and shallow soils. The largest increases are generally seen where production is low and small absolute gains can result in a large percentage increase.

b. Silvicultural Options.

All three reference sites are predicted to experience a drop in production. Results include output from 5 future climates.

Site A: Modelling suggests increasing the stocking to 1600ph at planting can increase productivity (~2.5%) but diameters were on average lower (46.1cm compared to the original option 48cm). The biggest productivity gains were seen when the number of thinnings was reduced to 2 and delayed several years (~5%). This resulted in average diameters of 48cm.

Site B: Modelling suggests there will be a small proportion of plantation failure (~5%) during severe drought (two consecutive years). Where plantations survived, the biggest productivity gains were seen when the number of thinnings was reduced to 2 and delayed several years (~11%), followed by increasing the stocking to 1600sph (~2.5%). Diameter distributions were broadly similar with diameters ~45cm.

Site C: At some locations there will be a high proportion of failures irrespective of silviculture, giving a bi-modal distribution of yields, with those that fail during critically dry years at one end of the scale and those that survive yielding modest production. Shorter rotations (23 years compared to 35) reduced the number of plantation failures by limiting exposure to drought, and increased productivity on average by 23%.

c. Fire.

Fire danger is characterised using the Forest Fire Danger Index (FFDI). For Victoria and Southern NSW FFDI is not predicted to change much during autumn but median FFDI may increase from August to April. The number of days with FFDI>25 suggests a lengthening of the fire season at both ends with the largest increases inland of the Australian Alps.

Risk Factor	Management strategy	Comments
Fire weather	Regional fire response plans	Climate change is expected to change the frequency and intensity of fires, but not the nature of fire
Fuel loads	Clean up debris from under plantations. Prune branches. Weed control	Maybe a strategy for high-risk areas
Fire spread	Landscape design can limit fire spread and aid suppression	Opportunities to avoid fire by relocating plantation estate were not identified

d. Pests

Pest damage may amplify negative effects of climate change on stand productivity. Pest damage in the region includes defoliation, stem and root damage. For 2 indicative sites (wetter and drier, and either low/medium or high fertility), it was predicted that, for stands experiencing defoliation, maximum reduction in final volume will average 10% at these sites (~110-170 m³/ha), with greatest impact occurring when defoliation is >60%, site fertility is low and at drier sites. There will be considerable between-site variability in responses, and later age defoliation will have a greater impact than early age defoliation. Multiple defoliations will have a substantially greater impact on volume than single events particularly at lower fertility sites.

Adaptation strategies can involve changes to management, viz:

Damage Type	Management strategy	Comments
Defoliation	Fertilise to promote crown recovery. Maintain biological control agent for Monterey pine aphid	May increase drought mortality risk
Stem damage	Thin plantations to manage drought stress. Reduce slash to manage population build-up. Maintain biological control agent for <i>Sirex</i> and <i>Ips</i>	Can help manage drought risk
All	Monitor populations and control when populations are high.	Requires understanding of threshold population numbers for risk monitoring and modelling