ECOTONES & ASSOCIATES
CLIMATE CHANGE PROJECT
CONTRACT EXTENSION

PROJECTED CLIMATE CHANGE IMPACTS FOR SWCC – DISCUSSION OF RAINFALL & TEMPERATURE CHANGE IN RELATION TO SWCC ASSETS

SOUTH WEST CATCHMENTS COUNCIL

Revised & Updated May 2015

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Leonie Offer (SWCC) has provided project support throughout; Mike Christensen and Jodie Deeley (SWCC) have provided assistance. Thanks to Jodie Deeley for checking the final draft. John Clark (CSIRO) has provided assistance with data provision from the CCIA website.

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Australian Government

Contents

INTRODUCTION

Original Brief & Response

Part 1 - Prepare MCAS-S map to show where predicted rainfall and temperature changes are expected to be highest and link this with SWCC asset map to show those assets that will likely be i) heavily affected, ii) somewhat affected, and iii) not affected

Product required by the end of June.

Proposed Work:

- 1 day preparation & some research to ensure we have some basis for the process.
- A couple of hours to prepare climate data at much finer scale raster and integrate SWCC asset data from Gaia.
- One day preparing simple MCAS-S Models integrating climate projections and Asset data.
- Create final maps & simple report (process description).

Project intention & Limitations

This is a very cursory examination of climate projections from a single model, using very simple MCAS models. It is intended to be used as a discussion starter. The reader should not take these projections in any other way.

Revision

The document has been revised (April 2015) to incorporate CMIP5 projections data. In doing so the MCAS-S models have been modified to reflect a narrower range of available datasets. They have also been changed to use Best Case and Worst Case models (GCMs) under RCP8.5 rather than using two different RCPs, and to use 2090 rather than 2080 due to data availability.

Revision Objectives

- To update SWCC's existing MCAS climate modelling from CMIP 3 to CMIP 5 for the Projected Climate Change Impacts for SWCC-Discussion of rainfall and temperature change in relation to SWCC assets report.
- Review Biosequestration layers (3.1.2, 3.1.3, 3.1.4) using CMIP 5 data and assess if there is any significant change from CMIP 3. (Note: Depending on the outcome of the comparison model further modelling maybe required in another contract)
- Deliver maps and their associated spatial layer(s)

CLIMATE CHANGE PROJECTIONS – SOME BACKGROUND

To understand the nature of climate change projections, it is important to understand that there are many different Global Climate Models (GCM's), and that they vary in their projections. The range of models, the variance in projections, the number of different climate variables and the range of time steps involved makes for an extremely complex field. Each GCM offers a reasonable approach to future climate, although these approaches may lead to differing projections. For this reason many assessments of climate change projections will refer to a suite of models rather than a single model.

One important point is that projections for certain climate attributes (such as rainfall) from one model should not be combined with attributes from a different model at the same time. In other words, you should not take the best case or the worst case for rainfall, temperature etc. from a range of models to make a case.

In this background we present some results from an assessment of projections from an *ensemble* of Global Climate Models (GCM's). These are taken from a regional climate report generated for the SWCC region a website run by the James Cook University eResearch Centre and Centre for Tropical Biodiversity and Climate Change[1]. That report, in part, collates results from 18 GCMs for a high and low RCP scenario (RCP4.5, RCP8.5) at 8 time steps between 2015 and 2085. Much of the text in in this background is paraphrased from the report.

In that report, they consider RCP8.5 to represent 'business as usual', and RCP4.5 to represent a low, potentially achievable emissions target. All explanations focus on the high scenario as it represents the best projection of our current trajectory. In the current report, we have used the RCP 8.5 scenario and representative individual GCMs.

Temperature

All of Australia is projected to experience warming in the future. Currently, the mean annual temperature for South West is 16.1°C, experiencing a range of averages between 14.9°C and 18.4°C. By 2085, temperature is projected to increase by 2.7°C to 18.9°C.

Figure 1 tracks increase of mean annual temperature in South West between 2015 and 2085.

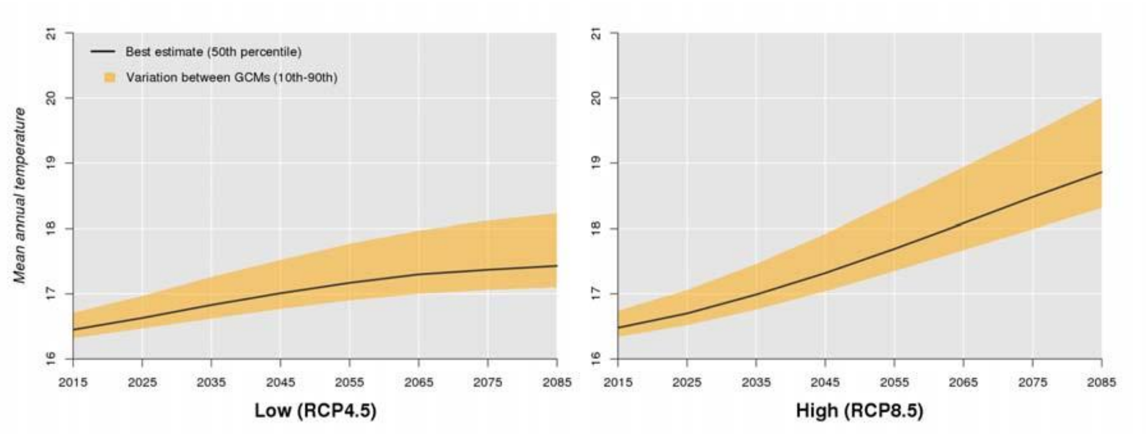

Figure 1- Increase of mean annual temperature in South West between 2015 and 2085, for Low (RCP4.5) and high (RCP8.5) scenarios. (JCU, 2013:1).

[1] Prepared by the James Cook University eResearch Centre and Centre for Tropical Biodiversity and Climate Change using species occurrence data from the Atlas of Living Australia (ALA) and climate layers derived from http://climascope.tyndall.ac.uk prepared by Jeremy VanDerWal.
To download a full report go to http://tdh-tools-2.hpc.jcu.edu.au/climas/reports.

There are significant projected increases in annual average temperature across South West, especially in high emission scenarios. Figure 2 shows images of the 10th, 50th and 90th percentiles to visualise the variation between the 18 different GCMs. The 10th percentile depicts the lower end of warming projected, at only 18.3°C (2.2°C increase), and the 90th percentile represents the high end of warming projected at 20°C (3.9°C increase) both for the high scenario.

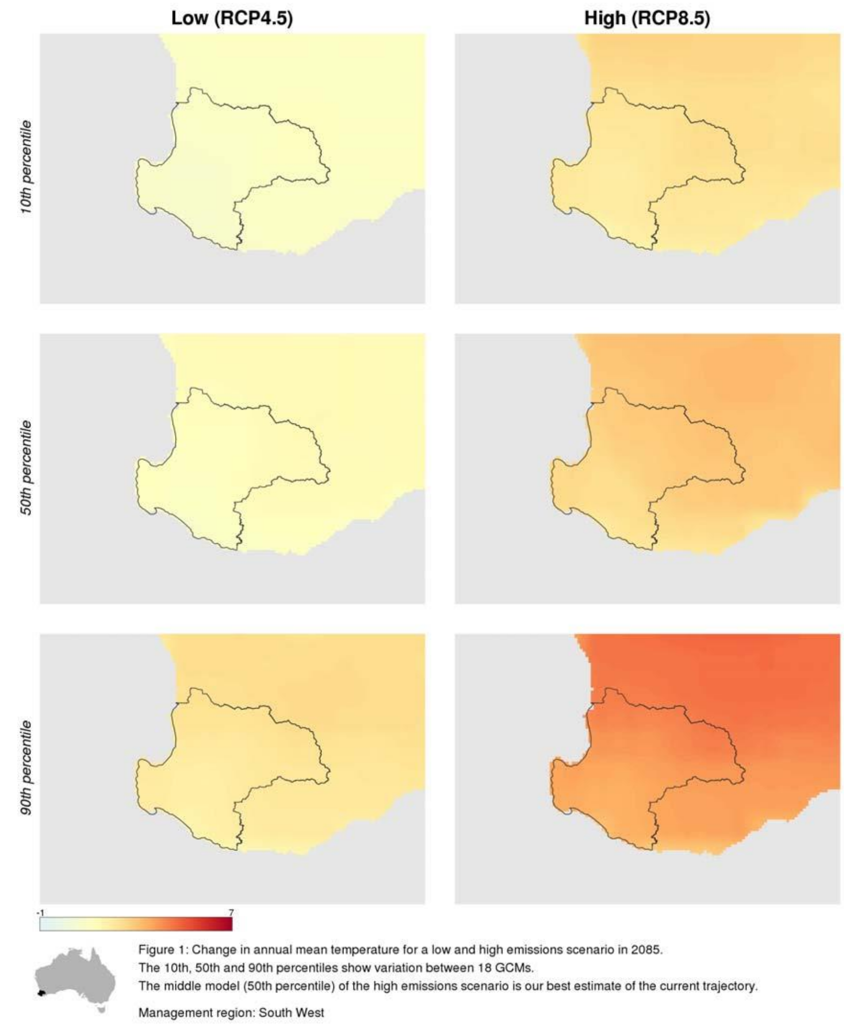

Figure 2- Projected increase in annual average temperature across South West, in low and high emission scenarios, for 10th, 50th and 90th percentile GCMs. (JCU, 2013:3)

Rainfall

Currently, the mean annual rainfall for South West is 729 mL, experiencing a range of averages between 347 mL and 1198 mL. Future rainfall projections are much more variable. By 2085, average rainfall is projected to decrease by 194 mL to 535 mL.

Figure 3 tracks decrease of rainfall in South West between 2015 and 2085. All models predict a decrease in rainfall, by between 340 mL and 101 mL.

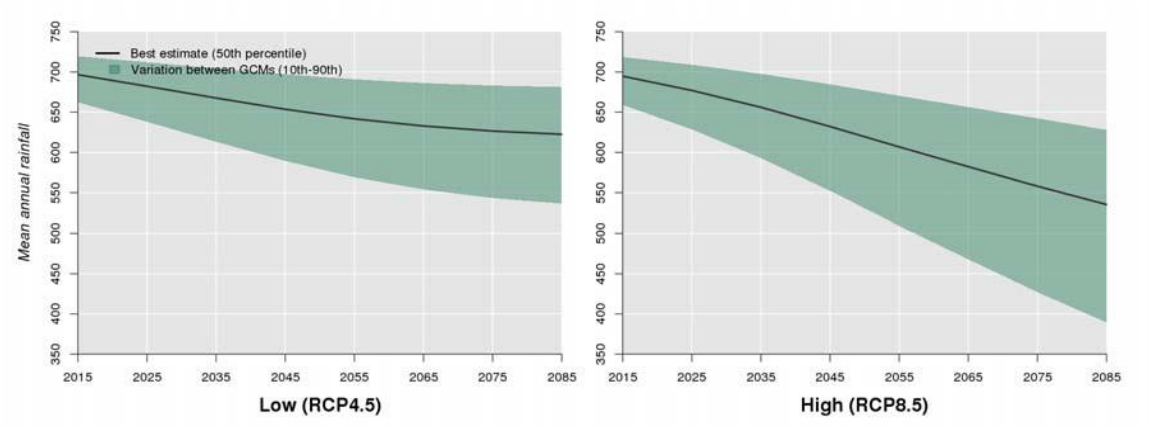

Figure 3 – Projected Increase of rainfall in South West between 2015 and 2085 for Low (RCP4.5) and high (RCP8.5) scenarios. (JCU, 2013:3).

Figure 4 shows the projected change in annual average rainfall across South West, in low and high emission scenarios.

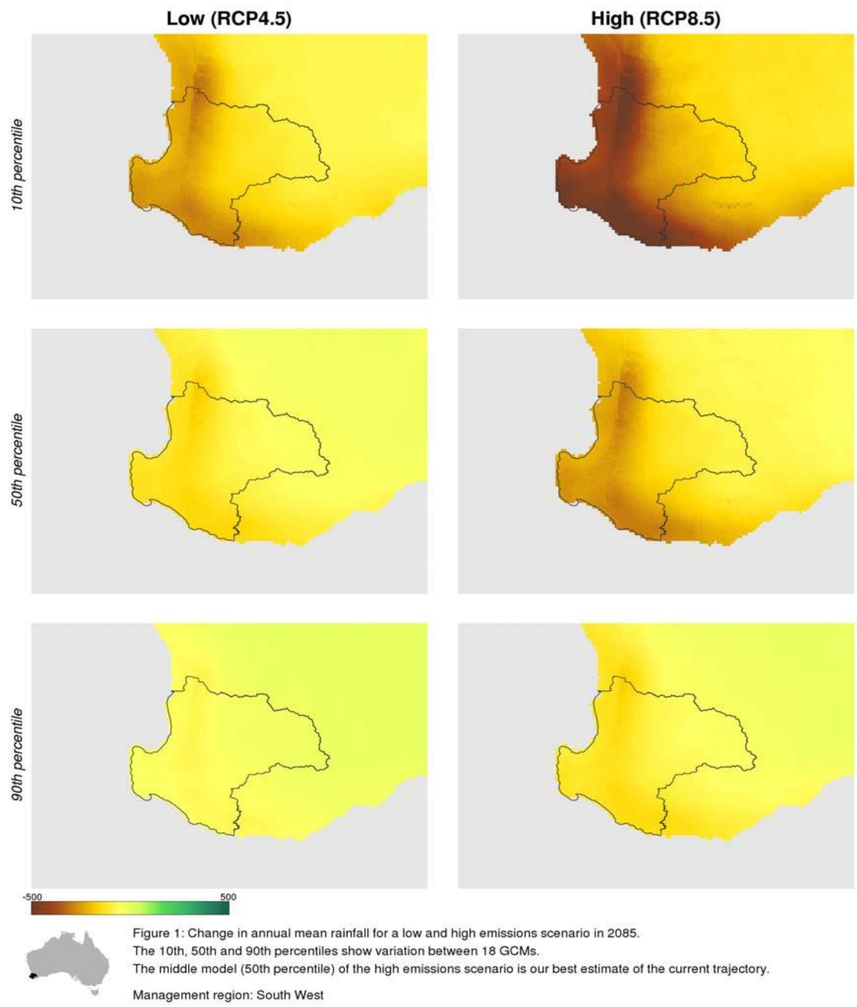

Figure 4– Projected change in annual average rainfall across South West, in low and high emission scenarios, for 10th, 50th and 90th percentile GCMs. (JCU, 2013:5).

As can be seen from these figures, there is a significant range of predictions for future climate across the SWCC region. Different GCMs vary in terms of severity of predictions. The general consensus is that the climate will warm if carbon emissions continue to rise (ie under RCP8.5), although the amount of predicted warming varies. The consensus for rainfall is that average rainfall will reduce over the region, again most strongly under a severe scenario – ie. if carbon emissions continue to rise strongly.

CLIMATE CHANGE PROJECTIONS

Model Selection

For this revised project we were tasked with selecting two Global Climate Models (GCMs) that provided good examples of the CMIP5 modelling for south west WA. The models should give both a best and worst-case indication, as well as being comparable to other climate modelling results.

The AdaptNRM project (Implications of Climate Change for Biodiversity – Williams et al 2014) uses two CMIP5 climate models—the Model for Interdisciplinary Research on Climate produced by the Japanese research community (MIROC5) and the Canadian Earth System Model (CanESM2). For both models, they project ecological change by 2050 under the emissions scenario defined by a Representative Concentration Pathway (RCP) of 8.5. We were mindful of these existing choices, but felt we had to independently evaluate models suitable for the SW of WA.

Model selection

The process used was facilitated by the Climate Change in Australia website from CSIRO, which contains tools for model evaluation and selection. The evaluation process is described in Appendix 2. Based on this assessment, we were comfortable in selecting models that have already been used by the AdaptNRM team in their bioclimatic modelling:

Case	Representative Model
Best Case	MIROC5
Worst Case	CanESM2
Maximum Consensus	ACCESS1-0

Table 1: Final Model Selection

Datasets Used

The following datasets were used previously for this project from the CMIP 3 data:

- Annual rainfall change,
- Annual rainfall change % change,
- May-October (growing season) rainfall,
- May-October rainfall change,
- May-October rainfall % change,
- Summer Maximum Temperature change
- *May-October Pan Evaporation change*
- *Summer Pan Evaporation change*
- Summer Evapo-Transpiration change

Those datasets in italics are not available in CMIP5 at this stage (or at all). We have therefore slightly modified the climate impact model used here to use the following datasets from the CMIP5 data:

Rainfall

- Annual rainfall change % change,
- *Annual rainfall change*
- May-October (growing season) rainfall,
- *May-October rainfall change*
- May-October rainfall % change

Annual rainfall change and percent change provide an overall rainfall change indication, while the three measures of May-October rainfall illustrate how growing season rainfall is changing both absolutely and relative to the area. The measure of total May-October rainfall provides an indication of how projected change may impact absolutely on cropping.

Temperature

- Summer Maximum Temperature change
- Annual Temperature change

Two measures of temperature is used – while mean annual temperature is affected by both summer and winter changes which may offset each other, a strong rise will have serious effects, and maximum summer temperature provides a single measure of stress in summer.

Effective Water availability

- Summer Evapo-Transpiration change

Evapotranspiration can be used as an indicator of another type of water stress – the extent to which water will be lost from water stores and the soil surface, and the extent to which changing weather will additionally stress plants.

The datasets in italics (rainfall change) were calculated from other datasets.

At this stage we have only downloaded and processed data from the three models to MCAS-S at 2090/RCP8.5, and for CanESM2 for 2030/RCP8.5.

SWCC ASSETS

The SWCC assets used here are two datasets: one is a set of existing native vegetation areas (under DPAW control) including national parks & nature reserves. The other is a biodiversity/conservation value assessment produced out of the MCAS Biosequestration modelling recently completed (Neville 2014).

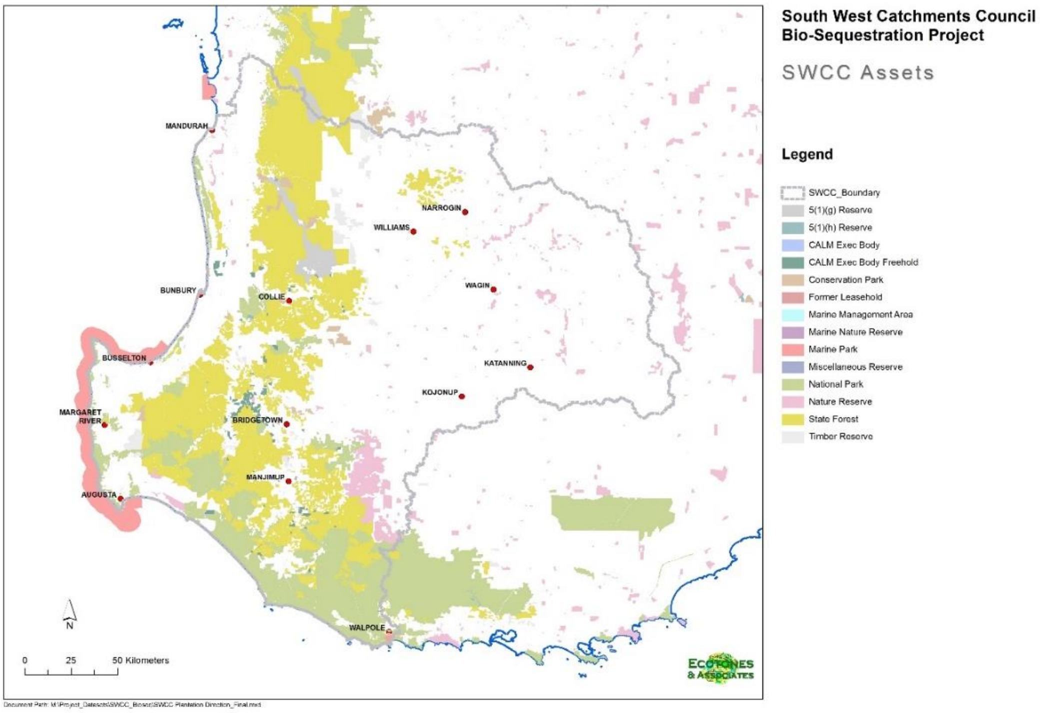

Figure 5 – SWCC Assets 1 – Natural Areas under DPAW management.

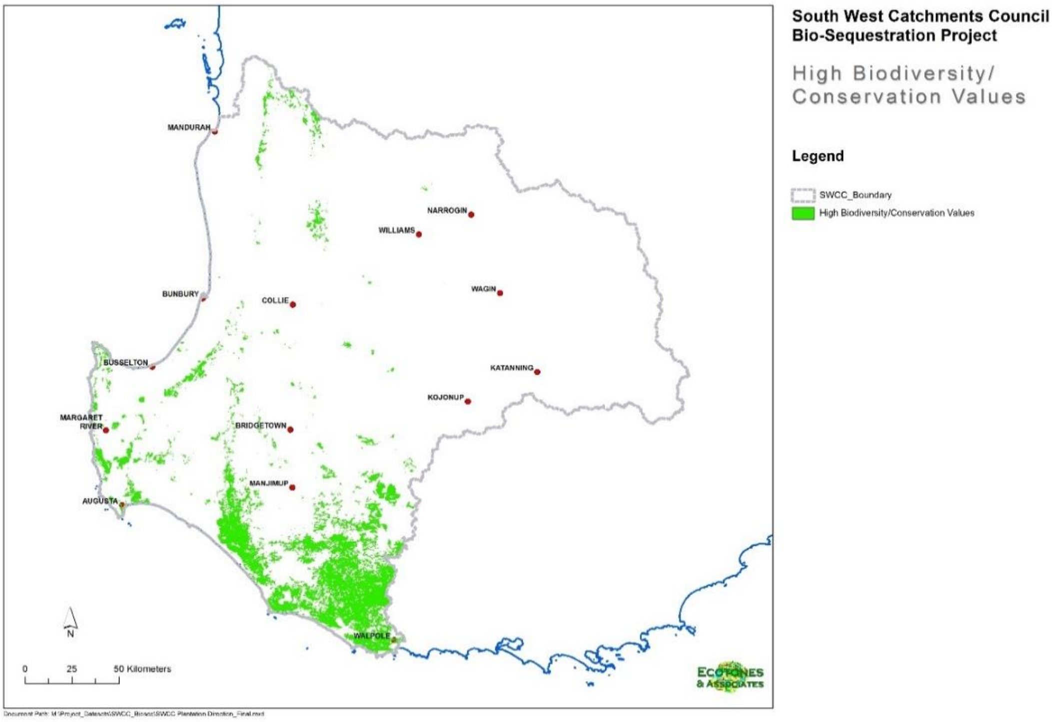

Figure 6 - SWCC Assets 2 –Areas defined as having high Biodiversity/Conservation Value through MCSS-S analysis (Neville 2014).

MCAS MODELLING

A single simple MCAS model was initially used to combine the various climate indications from the 2 GCMs. This model is an *indicative* look at how impacts may be spread across the SWCC region. It allows a single comparison of impacts between two models – initially representing lesser and greater degrees of future radiative forcing (A2 and A1B) associated with societal development. We now have revised the model to use two different GCMs (CanESM2 [Worst Case] and MIROC5 [Best Case]) at the same point in time (2090); and a second revision to compare a single model (CanESM2) at 2030 and 2090.

The model has been prepared as a demonstration only, and uses classification and weightings that are speculative and intended only as a demonstration.

Three sub-components have been used:

- Annual Rainfall stress,
- Growing Season Stress, and
- Maximum temperature stress.

'Annual Rainfall Stress' is generated from the sum of:

- 1 x 'rain_yr_ch' [Annual rainfall change] where a rainfall decline of >250mm is severe.
- 3 x 'rain_yr_pc_ch' [Annual rainfall change as a % of initial] where a drop of >25% is severe.

'Growing Season Stress' is generated from the sum of:

- 0.5 x ‘et mo pc change' [May-October evapo-transpiration change]
- 1 x 'rain_mo' [May-October rainfall] where a rainfall < 250mm is severe.
- 4 x 'rain_mo_ch' [May-October rainfall change] where a rainfall decline of >200mm is severe.
- 5 x 'rain_mo_pc_ch' [May-October rainfall change %] where a drop of >35% is severe.

Temperature Stress' is generated from the sum of:

- 2 x 'mxtmp_sm_chng' [Summer maximum temperature change] where an increase of >4deg. is severe.
- 1 x 'temp_yr_ch' [Temperature year change] where an increase of >4deg. is severe
- 1 x 'evaptrans_sum_change' [Summer evapo-transpiration change]

These sub-components are inputs for two composite layers:

- Indicative Climate stress, combining all three, and
- Indicative Non-Growing season stress, using just annual rainfall and maximum temperature.

'Indicative Climate Stress' is generated from the sum of:

- 2 x 'Annual Rainfall Stress'
- 3 x 'Growing Season Stress'
- 2 x 'Max Temp Stress'

'Indicative Non-growing season Stress' is generated from the sum of:

- 2 x 'Annual Rainfall Stress'
- 1 x 'Max Temp Stress'

The model is populated with the same datasets for each of the scenario/date options – and uses the same scales for each for comparison.

RESULTS

Comparison of Best Case (MIROC5) and Worse Case (CanESM2) models at 2090

The model comparing projected indicator change for 2090 under the best and worst case models is shown in full in Figure 7.

As would be expected, in general changes are indicated as being greater under the worst case scenario at 2090. Using the same scales, most of the impacts with the worst case register above impacts for the best case – notably with temperature – whereas projected annual rainfall reductions are similar for both models.

Annual Rainfall:

Under the Best Case, a loss of over 250mm in annual rainfall is projected for the northern Jarrah forest and the entire south-coast, while the projected percentage loss in rainfall is over 25% for the north-west of the region, and never less 20% for the entire SWCC region. Annual rainfall stress is significant the entire west of the region. While these impacts are significant, they are somewhat worse under the Worst Case. Almost the entire region is projected to have a greater than 25% drop in annual average rainfall: a reduction of over 250mm for the entire south and west.

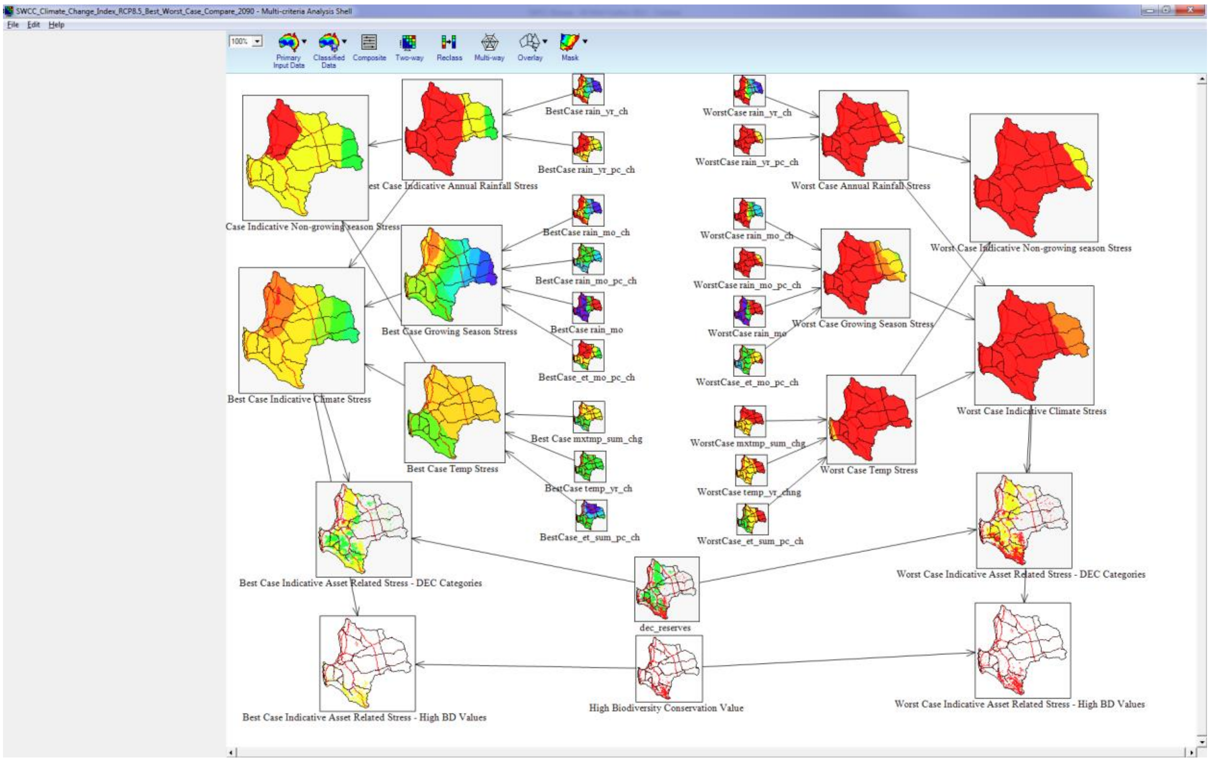

Figure 7 - MCAS Model for RCP8.5 – Best and Worst Case.

Growing Season:

Under the Best Case, a projected rainfall reduction of over 200mm – which is some 30% of current – gives the northern near-coastal areas the highest growing season stress risk. Growing season rainfall stress is also indicated for the southern coast, where percentage changes are projected to be between 25 and 30%. In the far East growing season rainfall is projected to drop below 250mm, but the percentage change is less.

Under the Worst Case, changes are projected to be significantly more severe. A projected rainfall reduction of over 200mm – which is some 30% of current – covers all of the west of the region. Growing season rainfall stress is also indicated for the southern coast, where percentage changes are projected to be between 25 and 30%. The area where growing season rainfall is projected to drop below 250mm extends almost to the center of the region.

Temperature Stress:

Under both Best Case and Worst Case, temperature stress is greatest in the north-eastern part of the region and grades south and west. However the amount of projected increase of both maximum and annual temperatures is significantly larger for the Worst Case: a maximum temperature increase of at least 3 degrees over the entire region, and up to 4.7 degrees in the north-east; and an annual increase of between 3 and 4.7 degrees for the region, verses 2-3 degrees for the Best Case.

Indicative Climate stress:

For the Best Case, this combination indicator peaks in the northwest of the region, and generally trends upwards moving from east to west. The area of least affect is in the far east of the region. This pattern is repeated for non-growing season stress. The pattern is repeated for the Worst Case, the difference being far high levels throughout the SWCC region.

Comparison of Worse Case (CanESM2) model at 2030 and 2090

The model comparing projected climate change for 2030 and 2090 under RCP8.5 for the CanESM2 GCM is shown in full in Figure 8.

The main conclusion to be drawn from this model is that under the worst case scenario, impacts are relatively limited at 2030 compared to 2090 – in particular growing season stress. Using the same scales, the outputs for 2030 register at the lower levels of the scales used to differentiate impacts at 2090. This is in accord with most observations that climate models indicate limited changes at 2030 compared to 2090. (It may however be at odds with anecdotal and real evidence of climate change in the SWCC region.) However, as discussed above, projected impacts for 2090 are significant.

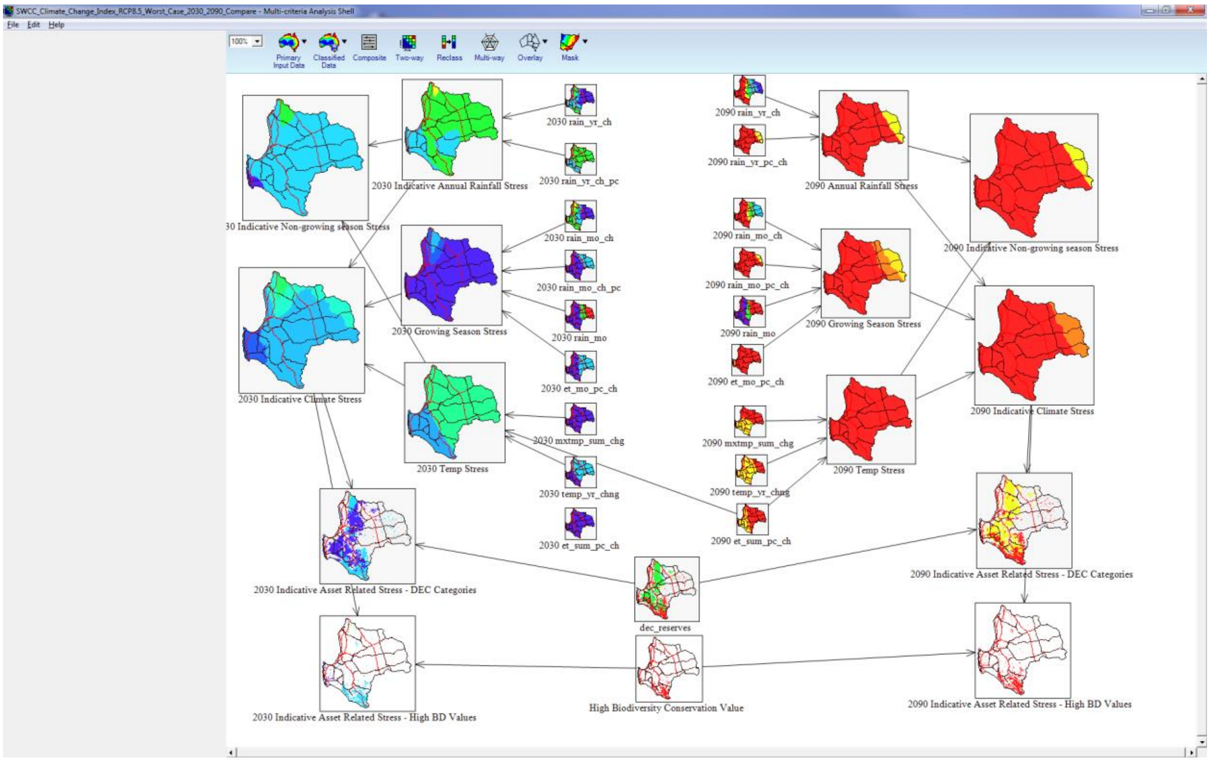

Figure 8 – MCAS Model for Worst Case at 2030 and 2090.

Rainfall:

For 2030, the projected changes for annual rainfall range from 62 to 191mm, highest along the south coast and in the northern darling ranges. The projected percentage reduction in rainfall ranges from 13% in the south-west

to 19% in the north-eastern edge of the SWCC region. The area of potential highest impact is in the north, with the south-west somewhat less affected. Apart from much higher levels of stress, the difference in 2090 is a strong trend to more severe impacts in the west. (This is not apparent with the scales used, but exists in the data).

Growing Season:

Projected changes in growing season rainfall for 2030 are similar in distribution to 2090, but much less pronounced. Growing season (May-October) rainfall reductions vary from 55 to 180mm, verses 81-380mm in 2090.

Temperature Stress:

The pattern of temperature stress is similar in 2030 to 2090 but much less severe, again greatest in the north-east of the region and grading southwest. But increases of between 0.9 and 1.1 degrees (max summer temp) for 2030 are far less than projected increases of 3.5 to 4.4 degrees in 2090. Perhaps more significantly, average annual temperatures are projected to increase by only 0.9 to 1.35 degrees in 2030 but by up to 4.3 degrees in 2090.

Indicative Climate stress:

This combination indicator in 2030 looks slightly different to 2090: peaking in the north and east of the region, with lower values along and to the east of the Leeuwin ridge. The values for the indicator are lower: a mean of 1.7 verses 5.5 means a much lower climate stress.

This result for non-growing season stress in 2030 are similar. The implications of these projections are that climate change will be relatively less pronounced in 2030.

ASSET RISK

We have combined the indicative climate stress for 2090 under MIROC5 (Best Case) and CanESM2 (Worst Case) scenarios with SWCC Assets.

The 'Indicative Asset Related Stress - High BD Values' layer is generated from 'Indicative Climate Stress' and 'High Biodiversity Conservation Value', where the value on the map simply repeats the indicative climate Stress.

'Indicative Asset Related Stress - DEC Categories' is generated with a Two Way MCAS tool, combining classifications from 'Indicative Climate Stress' and 'dec_reserves' to produce 5 classes of risk from 1=lowest to 5=highest:

	Indicative Climate Stress									
dec_reserves	1	1	2	2	3	3	4	4	5	5
	1	1	1	2	2	3	3	4	4	5
	1	1	1	1	2	2	3	3	4	4
	1	1	1	1	1	2	2	3	3	4
	1	1	1	1	1	1	1	1	1	1

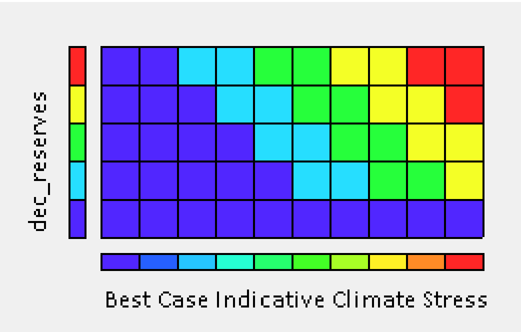

Figure 9 - Indicative Climate Stress 2-Way Matrix

The higher the indicative climate stress, the high the risk level.

Layer 'dec_reserves' is a categorical layer built from 'dec_reserves'

- Class 5 for Nature Reserve
- Class 5 for National Park
- Class 4 for Conservation Park
- Class 3 for State Forest
- Class 3 for Miscellaneous Reserve
- Class 3 for 5(1)(h) Reserve
- Class 3 for 5(1)(g) Reserve
- Class 2 for Timber Reserve
- Class 2 for Crown Freehold - Dept Interest
- Class 2 for CALM Exec Body Freehold
- Class 1 for Marine Park

The higher the class, the higher the risk level for a specific indicative climate stress.

RCP8.5 2090 - MIROC5 (Best Case)

Under the Best Case model, at least moderate levels of stress are indicated for all the high biodiversity areas, with 'highest' threat levels for all high biodiversity areas in the north the region. Risks to the DEC asset classes are also elevated in these areas, but are highest (in the two highest threat classes) in the north-west of the region. Note that significant threat is indicated throughout the region.

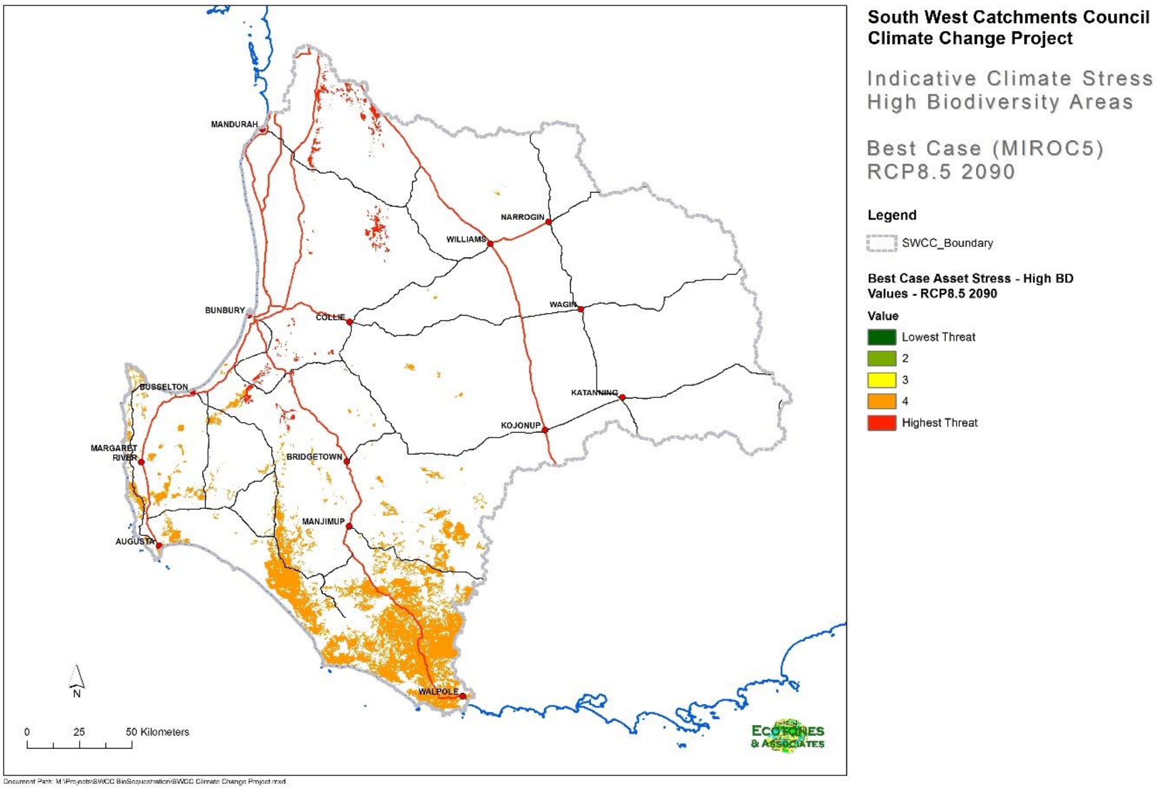

Figure 10 – Indicative Climate Threat, High Biodiversity Areas, Best Case RCP8.5 2090

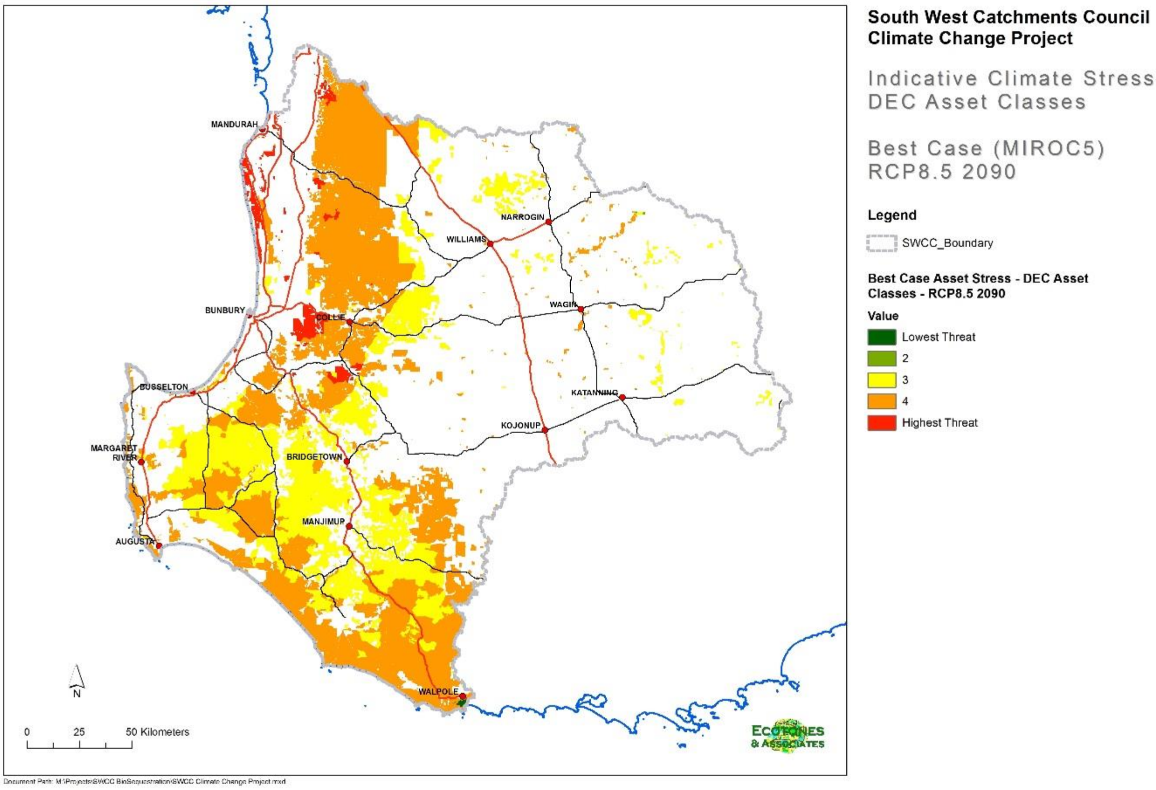

Figure 11 - Indicative Climate Threat, DEC Asset Classes, Best Case RCP8.5 2090

RCP8.5 2090 – CanESM2 (Worst Case)

Under the worst case model, highest levels of threat to high-biodiversity values are expressed throughout the region. Climate stress is in the highest class over the entire area, which translates to highest risk in areas where the DEC asset classes are also highest, and slightly lower for lower value assets. But threat is taken as being high or highest throughout the SWCC region.

If warming and drying are going to have impacts on SWCC assets as suggested by this impact model, then the entire region appears to be as risk.

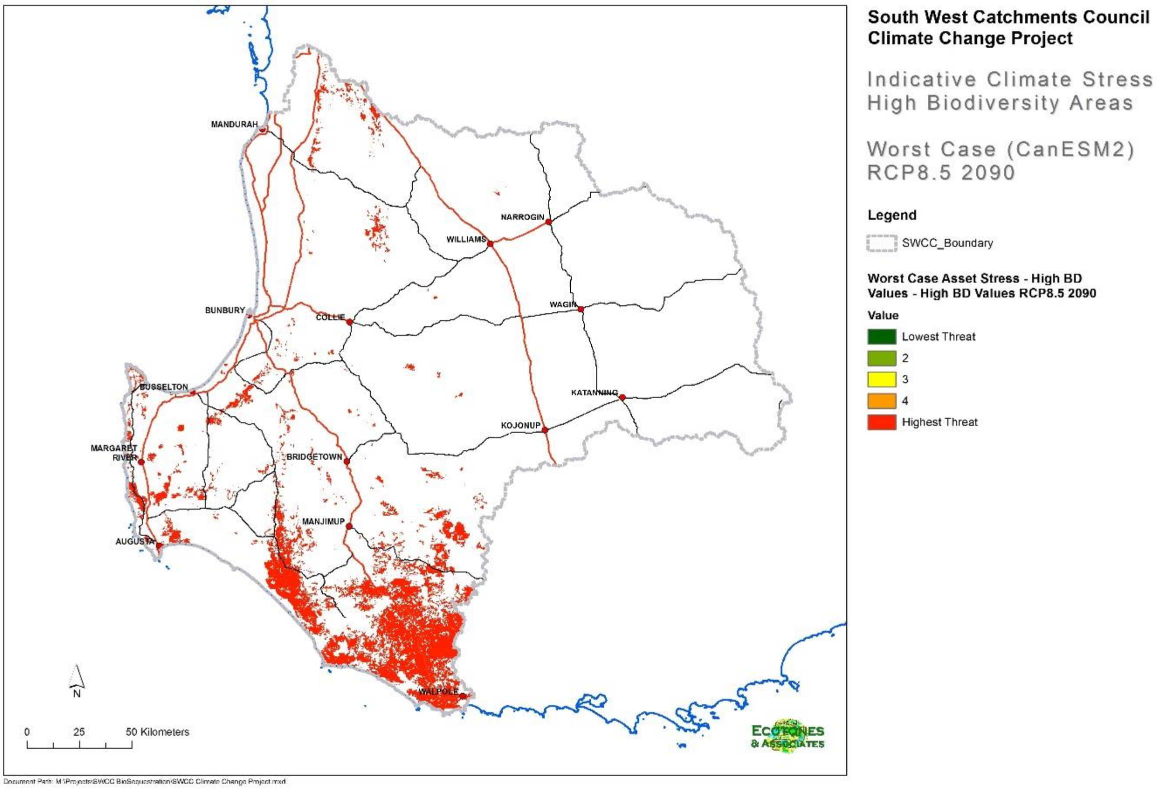

Figure 12 - Indicative Climate Stress, High Biodiversity Areas, Worst Case RCP8.5 2090

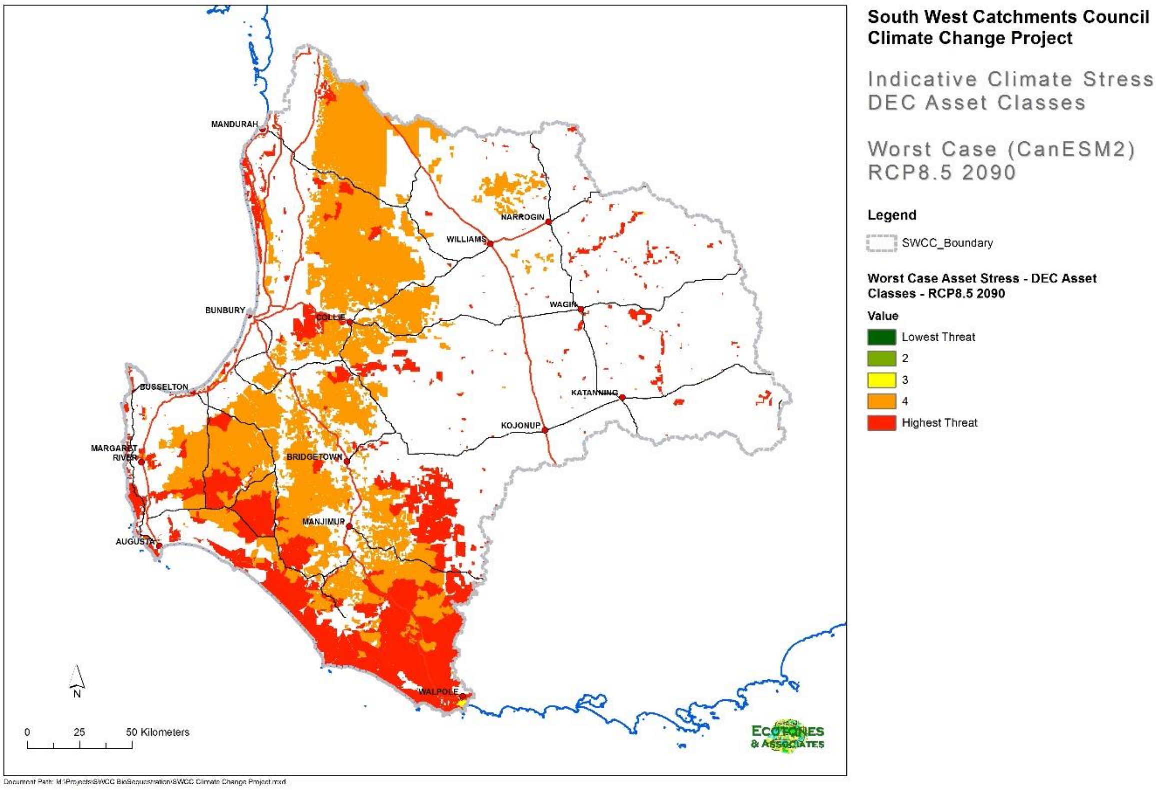

Figure 13 - Indicative Climate Threat, DEC Asset Classes, Worst Case RCP8.5 2090

Discussion

Alternative analysis, at a far more detailed level, has been done to identify climate refugia around Australia based on bioclimatic modelling of 1400 species in four classes of animals (mammals, reptiles, birds & amphibians: Reside et al 2013). This has been extended into modelling 'Ecological Change' by the AdaptNRM project by adding vascular plants and assessing measures of species assemblage change (Williams et al 2014). If we compare the simple model used here with the refugia study we see significant areas of agreement but some of disagreement, notably in the along the Darling Range, near Walpole, and in the east of the region, as shown in Figure 14. The comparison with the Vascular plant ecological risk modelling from the AdaptNRM modelling indicates broad areas of agreement, but these are now in the north and west of the region (see Figure 15).

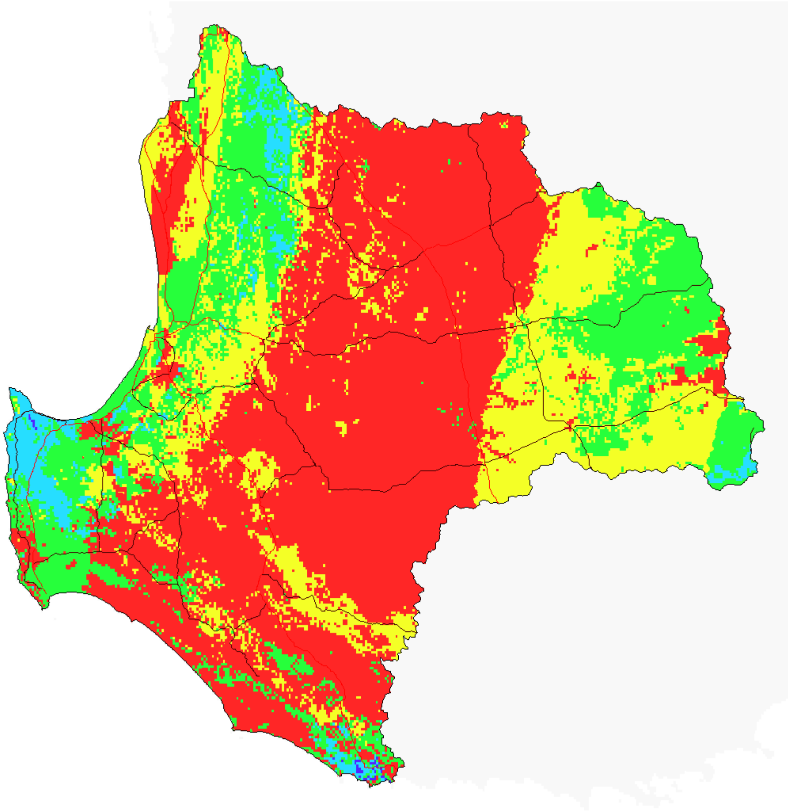

Figure 14 - Extent of Agreement between Best Case Indicative model and NCCARF Refugia. Red/Yellow indicates agreement, blue difference.

Possible reasons for these differences are many, one being that the model used here simply looks at change from present, rather than what an altered climate may have to offer potential immigrants. It does suggest that even this simple analysis has something to offer in suggesting where climate stress will be most severe.

Again, we have to note that the model used here is very simple, and hence the use of the term "indicative". It is useful as a discussion-starter, but for a better and more sophisticated understanding of the potential nature climate change impacts much more detailed work should be done using the range of models available.

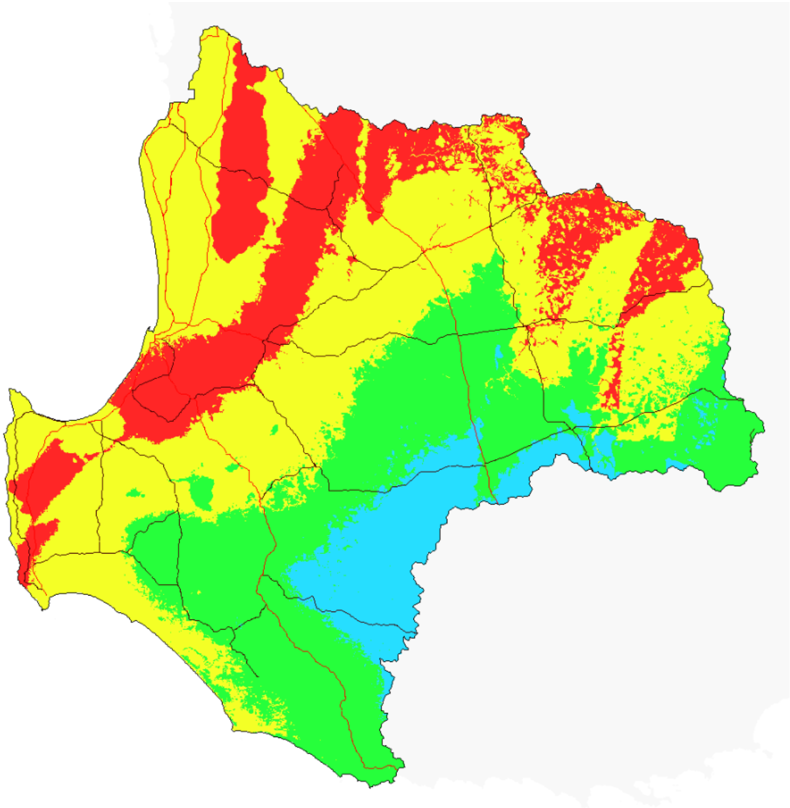

Figure 15 - Extent of Agreement between Best Case Indicative model and AdaptNRM Ecological Impact – Vascular Plants. Red/Yellow indicates agreement, blue difference.

REVIEW OF BIOSEQUESTRATION WORK RE CMIP5

The revision required a review of Biosequestration layers (3.1.2, 3.1.3, 3.1.4) developed during 2014 in the light of newly-available CMIP 5 data. We were required to assess if there is any significant change from CMIP 3.

SWCC Component 1 – Landscape for Protection

Contains no CMIP3- related datasets.

SWCC Component 2 – Locations for Low Biodiversity Plantings

Contains no CMIP3- related datasets.

SWCC Component 3 - High Biodiversity Conservation Values

Contains no CMIP3- related datasets. The Refugia dataset used was developed from CMIP5 data.

SWCC Component 4 – Areas for Biodiversity Plantings

Contains no CMIP3- related datasets.

SWCC Component C1 – Climate Impacts

This does contain CMIP3- related datasets in the form of the CENRM produced Plant Refugia, Plant Emigrants and Plant Immigrants. We are not in a position to update this work, as this would require the CENRM project (bioclimatic modelling) to be largely re-done.

An alternative update route is to substitute these datasets with 'Composite Ecological Change' datasets from the AdaptNRM Implications of Climate Change for Biodiversity project (Williams et al 2014). Examples of these are shown in the figure below. This data is available online.

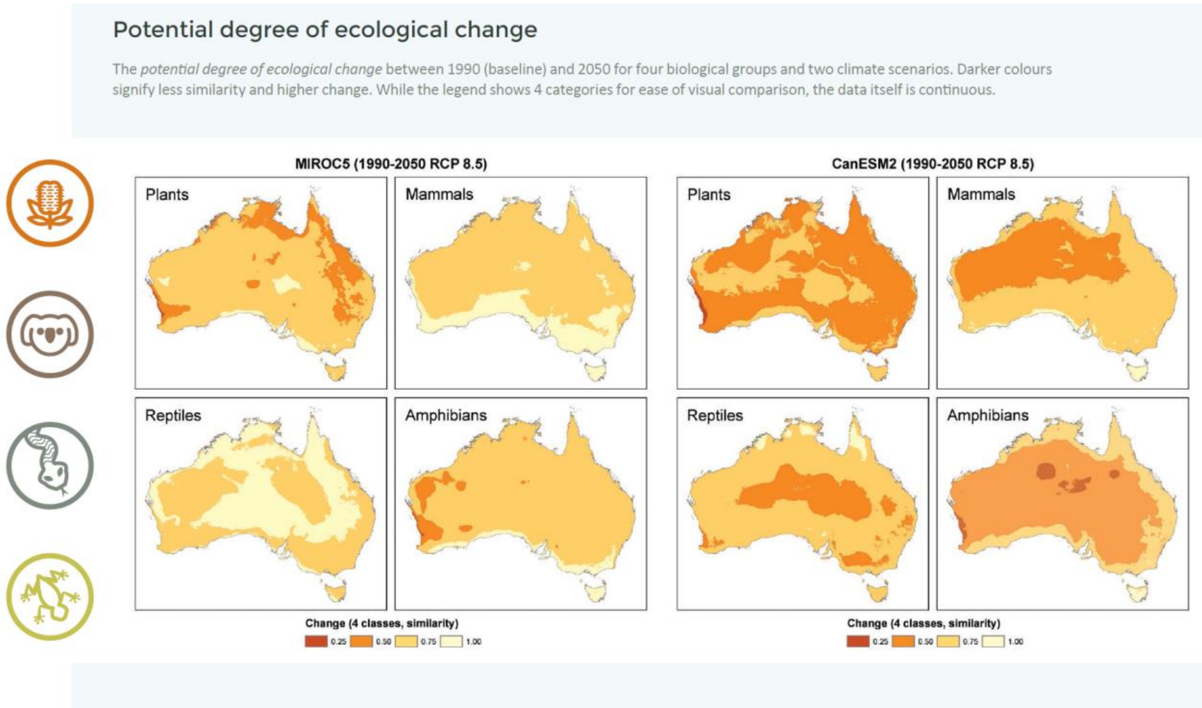

Figure 16: Potential Degree of Ecological Change datasets. Williams et al 2014:18)

Recommendation

Most of the existing MCAS components do not require any updating, however C1 can be updated and potentially improved using CMIP5-based datasets from AdaptNRM.

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APPENDIX 1 – GLOBAL CLIMATE MODEL (GCM) SELECTION

The AdaptNRM project reporting (Implications of Climate Change for Biodiversity) uses two CMIP5 climate models—the Model for Interdisciplinary Research on Climate produced by the Japanese research community (MIROC5) and the Canadian Earth System Model (CanESM2). For both models, they project ecological change by 2050 under the emissions scenario defined by a Representative Concentration Pathway (RCP) of 8.5.

CSIRO Climate Change in Australia (CCIA) Website

CSIRO/BOM selected eight out of the 40 CMIP5 models assessed in their project for use in provision of application-ready data. This facilitates efficient exploration of climate projections for Australia. A number of steps were considered in the model selection process:

- Rejection of models that were found to have a low performance ranking across a number of metrics and in some other relevant assessments (see Chapters 5 & 9 of the CCIA Technical Report for a full description).
- Selection of models for which projection data were available for climate variables commonly used in impact assessments, for at least RCP4.5 and RCP8.5.
- Identification of models that are representative of the range of seasonal temperature and rainfall projections for a climate centered on 2050 and 2090 and RCP4.5 and RCP8.5 using the Australian Climate Futures software.
- Projections for wind were assessed separately from temperature and rainfall to ensure the CMIP5 range was captured. This is because the direction and magnitude of wind projections are not necessarily correlated with the temperature and/or rainfall projections.
- Availability of corresponding statistical or dynamical downscaled data.
- Consideration of the independence of the models.

The selected CMIP5 models and reasons for their inclusion are given in the table below.

SELECTED MODELS	CLIMATE FUTURES	OTHER
ACCESS1.0	Maximum consensus for many regions.	The model exhibited a high skill score with regard to historical climate.
CESM1-CAM5	Hotter and wetter, or hotter and least drying	This model was representative of a low change in an index of the Southern Annular Mode (per degree global warming). Further, the model has results representing all RCPs.
CNRM-CM5	Hot /wet end of range in Southern Australia	This model was representative of low warming/dry SST modes as described in Watterson (2012) (see Section 3.6). It also has a good representation of extreme El Niño in CMIP5 evaluations (see Cai et al. (2014)).
GFDL-ESM2M	Hotter and drier model for many clusters	This model was representative of the hot/dry SST mode as described in (Watterson, 2012) (see Section 3.6). It also has a good representation of extreme El Niño in CMIP5 evaluations (see Cai et al. (2014)). Further, the model has results representing all RCPs.
HadGEM2-CC	Maximum consensus for many regions.	This model has good representation of extreme El Niño in CMIP5 evaluations (see Cai et al. (2014)
CanESM2		This model was representative of the hot/wet SST mode as described in Watterson (2012) (Section 3.6). It also has a high skill score with regard to historical climate and it increased representation of the spread in genealogy of models (Knutti et al., 2013). It also has good representation of extreme El Niño in CMIP5 evaluations (Cai et al., 2014).
MIROC5 (non-commercial use only)	Low warming wetter model	This model was representative of a higher change in an index of the Southern Annular mode (per degree global warming). It also has good representation of extreme El Niño in CMIP5 evaluations (see Cai et al. (2014)). Further, the model has results representing all RCPs.
NorESM1-M	Low warming wettest representative model	This model was representative of the low warming/wet SST mode as described in Watterson (2012) (see Section 3.6). The model also has results representing all RCPs.

Table 2: CCIA Selected CMIP5 models and reasons for their inclusion.

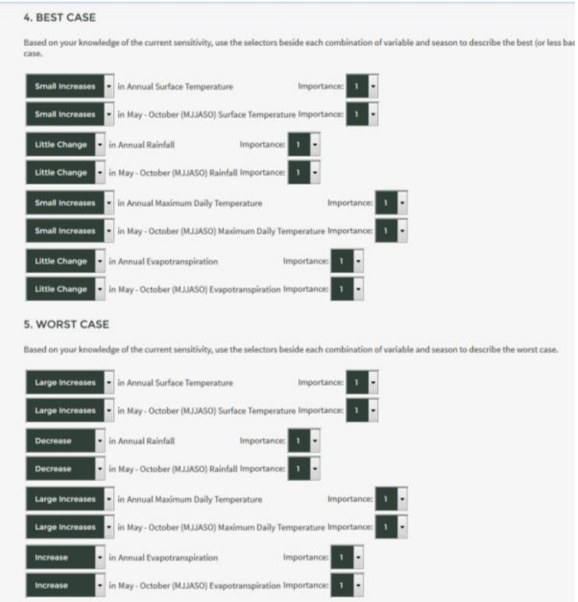
Source: Box 9.2 of the CCIA Technical Report. References are on the CCIA website.

This selection of models means that we are limited to accessing these results from the CSIRO/BOM "Climate Change in Australia" website[2]. This limits the amount of selection we have to undertake, and we can be satisfied that they have done a lot of preliminary assessment to arrive at this shortlist.

Model selection – Projections Builder.

In order to select the models to use, we accessed the Projections Builder on the CSIRO Climate Change in Australia Website. We then identified what datasets were required, and ranked the importance of variable in the assessment. This was done in two ways, one increasing the weighting of rainfall to double that of other variables as shown below.

Model Selection Factors - All equal



Model Selection Factors – Rainfall weighted

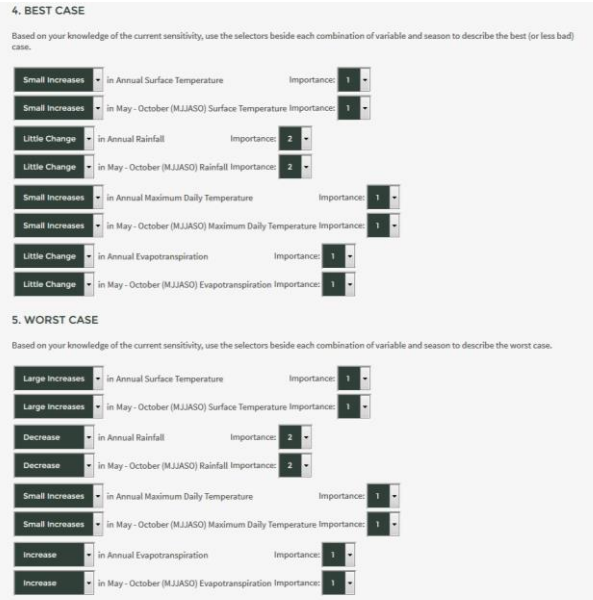


Figure 17: Model Selection Factors

[2] In time results from all the models will be available from the CCIA website, but at the time of this study this was the case.

Representative Models

For the purpose of impact analysis, we need to make a selection of models – it is not practical to use the full range available – and in fact there are numerous models whose results are not suitable for Australia (see Appendix 1).

We need to use the range of future scenarios, and we have selected RCP4.5 and 8.5 as representative of the plausible future pathways (RCP2.6 is generally considered quite unrealistic).

It is important to avoid mixing results from different models in impact analysis; instead we should be providing alternate analyses based on specific models as shown below.

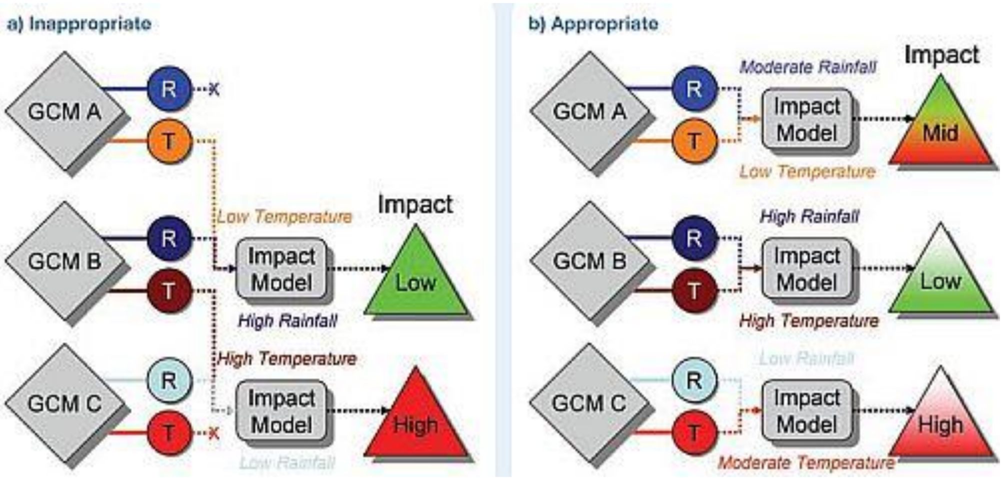


Figure 18 - Example of appropriate and inappropriate use of climate model projections in impact assessment (CCIA 2015).

For this reason we need to identify suitable models to represent the range of possible futures as represented in different by the different teams. According to Andy Reisinger, one of the authors of the IPCC fifth assessment science report, it is critical to identify impacts based on the range of possible futures. For this reason he states that we should look at best- and worst-case scenarios as well as a mid-consensus model for our impact assessment (Reisinger, Pers. Comm. 2014).

To identify the representative models, the CCIA website tool ranks all models using a multivariate statistical technique (Kokic et al., 2002) to identify the model that is the best fit to the settings selected by the user for the Best and Worst cases.

In addition, where possible, the tool identifies the maximum consensus climate future (i.e. the climate future projected by at least 33% of the models and which comprises at least 10% more models than any other).

We ran the website tool for RCP 4.5 and 8.5 for 2030 and 2090 (some datasets are not available at 2080 at present) in order to see what models were selected as best and worst case, as well as highest consensus models.

2030 Models

For the 2030 RCP4.5 base for the Southern and South-Western Flatlands, the tool selects the following models:

Case	Representative Model	Consensus
Best Case	NorESM1-M	Moderate
Worst Case	GFDL-ESM2M	Very Low
Maximum Consensus	ACCESS1-0	Moderate

Table 3: RCP4.5 2030 Models Base Case - Representative models.

	Model	Surface Temperature		Rainfall		Maximum Daily Temperature		Evapotranspiration	
		Annual	May - October (MJJASO)	Annual	May - October (MJJASO)	Annual	May - October (MJJASO)	Annual	May - October (MJJASO)
Best Case	NorESM1-M	0.68°C	0.68°C	-1.9%	-7.1%	0.77°C	0.80°C	2.9%	3.1%
Worst Case	GFDL-ESM2M	0.97°C	0.88°C	-32.2%	-23.7%	1.10°C	0.99°C	1.5%	2.8%
Maximum Consensus	ACCESS1-0	0.82°C	0.77°C	-8.0%	-7.6%	0.94°C	0.91°C	2.7%	2.2%

Table 4: RCP4.5 2030 Models - Projected changes for each of the selected variables and seasons

For the 2030 RCP4.5 Rainfall for the Southern and South-Western Flatlands, the tool selects the following models:

Case	Representative Model	Consensus
Best Case	NorESM1-M	Moderate
Worst Case	GFDL-ESM2M	Very Low
Maximum Consensus	ACCESS1-0	Moderate

Table 5: RCP4.5 2030 Models Rainfall Weighted Case - Representative models

For the 2030 RCP8.5 base for the Southern and South-Western Flatlands, the tool selects the following models:

Case	**Representative Model**	**Consensus**
Best Case	MIROC5	Moderate
Worst Case	CanESM2	Moderate
Maximum Consensus	NorESM1-M	Moderate

Table 6: RCP8.5 2030 Models Base Case - Representative models

	Model	Surface Temperature		Rainfall		Evapotranspiration	
		Annual	May - October (MJJASO)	Annual	May - October (MJJASO)	Annual	May - October (MJJASO)
Best Case	MIROC5	0.75°C	0.71°C	-0.4%	-4.2%	3.1%	4.1%
Worst Case	CanESM2	1.31°C	1.20°C	-14.8%	-17.2%	4.7%	8.3%
Maximum Consensus	NorESM1-M	0.79°C	0.75°C	-5.9%	-11.1%	2.9%	3.8%

Table 7: RCP8.5 2030 Models - Projected changes for each of the selected variables and seasons.

For the 2030 8.5 Rainfall-weighted scenario, the tool offers the following models:

Case	Representative Model	Consensus
Best Case	MIROC5	Moderate
Worst Case	CanESM2	Moderate
Maximum Consensus	NorESM1-M	Moderate

Table 8: RCP8.5 2030 Models Rainfall Case - Representative models.

2090 Models

For the 2090 RCP4.5 base scenario, the tool offers the following models:

Case	Representative Model	Consensus
Best Case	MIROC5	Low
Worst Case	GFDL-ESM2M	Very Low
Maximum Consensus	ACCESS1-0	Moderate

Table 9: RCP4.5 2090 Models Base Case - Representative models.

	Model	Surface Temperature		Rainfall		Maximum Daily Temperature		Evapotranspiration	
		Annual	**May - October (MJJASO)**	**Annual**	**May - October (MJJASO)**	**Annual**	**May - October (MJJASO)**	**Annual**	**May - October (MJJASO)**
Best Case	MIROC5	1.37°C	1.24°C	-1.3%	-1.6%	1.49°C	1.37°C	4.6%	5.7%
Worst Case	GFDL-ESM2M	1.21°C	1.41°C	-21.8%	-28.4%	1.43°C	1.73°C	3.0%	3.7%
Maximum Consensus	ACCESS1-0	1.91°C	1.82°C	-8.6%	-11.8%	2.04°C	1.99°C	6.3%	7.0%

Table 10: RCP4.5 2090 Models - Projected changes for each of the selected variables and seasons

For the 2090 RCP4.5 Rainfall-weighted scenario, the tool offers the following models:

Case	Representative Model	Consensus
Best Case	MIROC5	Low
Worst Case	GFDL-ESM2M	Very Low
Maximum Consensus	ACCESS1-0	Moderate

Table 11: RCP4.5 2090 Models Rainfall Case - Representative models.

For 2090 in RCP8.5, using the base and the rainfall enhanced settings, the tool selects the same three models:

Case	**Representative Model**	**Consensus**
Best Case	MIROC5	Low
Worst Case	GFDL-ESM2M	Very Low
Maximum Consensus	ACCESS1-0	Moderate

Table 12: RCP8.5 2090 Models both Cases - Representative models.

	Model	**Surface Temperature**		**Rainfall**		**Maximum Daily Temperature**		**Evapotranspiration**	
		Annual	**May - October (MJJASO)**	**Annual**	**May - October (MJJASO)**	**Annual**	**May - October (MJJASO)**	**Annual**	**May - October (MJJASO)**
Best Case	MIROC5	2.67°C	2.51°C	-6.4%	-13.2%	2.83°C	2.79°C	9.3%	11.9%
Worst Case	GFDL-ESM2M	2.87°C	2.96°C	-44.5%	-49.5%	3.19°C	3.37°C	7.1%	8.5%
Maximum Consensus	ACCESS1-0	3.58°C	3.59°C	-29.2%	-35.8%	3.84°C	4.05°C	10.0%	13.3%

Table 13: RCP8.5 2090 Models - Projected changes for each of the selected variables and seasons

		Best Case	**Worst Case**	**Maximum Consensus**
2030	RCP4.5 Base	NorESM1-M	GFDL-ESM2M	ACCESS1-0
	RCP4.5 Rainfall	NorESM1-M	GFDL-ESM2M	ACCESS1-0
	RCP8.5 Base	MIROC5	CanESM2	NorESM1-M
	RCP8.5 Rainfall	MIROC5	CanESM2	NorESM1-M
2090	RCP4.5 Base	MIROC5	GFDL-ESM2M	ACCESS1-0
	RCP4.5 Rainfall	MIROC5	GFDL-ESM2M	ACCESS1-0
	RCP8.5 Base	MIROC5	GFDL-ESM2M	ACCESS1-0
	RCP8.5 Rainfall	MIROC5	GFDL-ESM2M	ACCESS1-0

Table 14: Collated Results from the Climate Projections tool.

From this table we can see that the indicated model sets vary depending on date and RCP, but not due to the higher weighting for rainfall. Five models are selected in total, but we can only cover three for the two time periods. Given that the AdaptNRM project has already made model selections for a more/less severe future (CanESM2/MIROC5 respectively) we are inclined to use these models in the same roles. While CanESM2 is selected as "Worst Case' model by the Climate Projections tool in only 2 of the eight scenarios examined, we can see from the Climate Futures tool that it is very similar to GFDL-ESM2M.

The Climate Futures tool can be used to examine any scenario/date combination to see where the Climate models cluster on a two-variable table (Temperature vs Rainfall was used here). We used this tool to look at the same set of scenarios/timeframes as before, and established how the eight models available perform in comparison to all models. This performance is shown in the following table.

Selected Models	2030 RCP 4.5	2030 RCP 8.5	2090 RCP 4.5	2090 RCP 8.5
ACCESS1.0	Warmer/Little Change	Warmer/Little Change	Hotter/Drier	Much Hotter/Much Drier
CESM1-CAM5	Warmer/Little Change	Warmer/Little Change	Hotter/Drier	Much Hotter/Much Drier
CNRM-CM5	Warmer/Little Change	Warmer/wetter	Hotter/Wetter	Much Hotter/Drier
GFDL-ESM2M	Warmer/Little Change	Warmer/much drier	Warmer/Much drier	Hotter/Much Drier
HadGEM2-CC	Warmer/Drier	Warmer/Drier	Hotter/Drier	Much Hotter/Much Drier
CanESM2	Warmer/Drier	Warmer/Drier	Hotter/Drier	Much Hotter/Much Drier
MIROC5	Warmer/Little Change	Warmer/Little Change	Warmer/Little Change	Hotter/Drier
NorESM1-M	Warmer/Little Change	Warmer/Drier	Warmer/Little Change	Hotter/Little Change

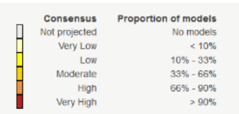


Table 15 – CSIRO Selected Model performance relative to other GCMS for Southern and South-Western Flatlands. Models used by AdaptNRM in italics.

From this it is clear that ACCESS1 is well suited as the high consensus model. CanESM2 is also placed within a moderate consensus, even though it is quite severe. MIROC5 – the selected best case model above – is a slightly lower consensus model, especially at 2090.

Case	Representative Model
Best Case	MIROC5
Worst Case	CanESM2
Maximum Consensus	ACCESS1-0

Table 16: Final Model Selection

APPENDIX 2 – MCAS MODEL PARAMETERS

Layer ‘Annual Rainfall Stress' is a composite layer producing 5 classes
The composite function is generated from the sum of:
1 x 'WorstCase rain_yr_ch'
3 x 'WorstCase rain_yr_pc_ch'
The result is classed according to this table:
1 - up to 1
2 - up to 1.5
3 - up to 2
4 - up to 2.5
5 - above 2.5

Layer 'Growing Season Stress' is a composite layer producing 10 classes
The composite function is generated from the sum of:
1 x 'WorstCase rain_mo'
4 x 'WorstCase rain_mo_ch'
5 x 'WorstCase rain_mo_pc_ch'
0.5 x 'WorstCase_et_mo_pc_ch'
The result is classed according to this table:
1 - up to 3
2 - up to 3.5
3 - up to 4
4 - up to 4.5
5 - up to 5
6 - up to 5.5
7 - up to 6
8 - up to 6.5
9 - up to 7
10 - above 7

Layer 'Temp Stress' is a composite layer producing 6 classes
The composite function is generated from the sum of:
2 x 'WorstCase mxtmp_sum_chg'
1 x 'WorstCase temp_yr_chng'
1 x 'WorstCase_et_sum_pc_ch'
The result is classed according to this table:
1 - up to 0.5
2 - up to 1
3 - up to 1.5
4 - up to 2
5 - up to 2.5
6 - above 2.5

These sub-components are inputs for two composite layers:

- Indicative Climate stress, combining all three, and
- Indicative Non-Growing season stress, using just annual rainfall and maximum temperature.

Layer 'Indicative Climate Stress' is a composite layer producing 10 classes
The composite function is generated from the sum of:
2 x 'Best Case Temp Stress'
3 x 'Best Case Growing Season Stress'
2 x 'Best Case Indicative Annual Rainfall Stress'
The result is classed according to this table:

1 - up to 1
2 - up to 1.5
3 - up to 2
4 - up to 2.5
5 - up to 3
6 - up to 3.5
7 - up to 4
8 - up to 5
9 - up to 6
10 - above 6

Layer 'Indicative Non-growing season Stress' is a composite layer producing 5 classes
The composite function is generated from the sum of:
1 x 'Best Case Temp Stress'
2 x 'Best Case Indicative Annual Rainfall Stress'
The result is classed according to this table:
1 - up to 1
2 - up to 1.5
3 - up to 2
4 - up to 2.5
5 - above 2.5

The model is populated with the same datasets for each of the three scenario/date options – RCP8.5 CanESM2 at 2030 and 2090, and RCP8.5 MIROC5 at 2090 – and uses the same scales for each for comparison.