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McArthur River Mine
Overburden Management Project

Appendix D
Climate Change Assessment Methodology

Draft Environmental Impact Statement

Approach for Assessing Climate Change Impacts for the MRM OMP EIS

McArthur River Mining Pty Ltd

0790-17-V2, 10 January 2017

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NOTE: This report has been prepared on the assumption that all information, data and reports provided to us by our client, on behalf of our client, or by third parties (e.g. government agencies) is complete and accurate and on the basis that such other assumptions we have identified (whether or not those assumptions have been identified in this advice) are correct. You must inform us if any of the assumptions are not complete or accurate. We retain ownership of all copyright in this report. Except where you obtain our prior written consent, this report may only be used by our client for the purpose for which it has been provided by us.

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1 Introduction

The assessment of climate change impacts is a key risk management task for the McArthur River Mine (MRM) Overburden Management Project (OMP) Environmental Impact Statement (EIS) project (the project). The MRM OPM EIS will investigate potential climate change impacts on the project across all relevant technical disciplines using the agreed climate change impact assessment approach.

MRM requested WRM Water & Environment (WRM) to develop the approach to assess the potential impacts of climate change on the project. This report is in response to this request.

2 Literature review

2.1 GENERAL

The Australian Government have released a number of reports on managing the risks of a variable and changing climate in Australia. A desktop review of available and relevant climate change information from the Australian Government Department of Environment, Australian Bureau of Meteorology and CSIRO reports is presented below.

2.2 COMMONWEALTH DEPARTMENT OF ENVIRONMENT REPORT (DOE, 2015)

2.2.1 Overview

The Commonwealth Department of the Environment (DoE) have released a report entitled "*national climate resilience and adaptation strategy*" (DoE, 2015) on 2 December 2015 (accessed on 21 December 2015). The Strategy sets out how Australia is managing climate risks for the benefit of the community, economy and environment. It identifies a set of principles to guide effective adaptation practice and resilience building, and outlines the Government's vision for the future.

2.2.2 Findings

With respect to the potential water resources impacts due to a changing climate, the DoE report finds that:

- Our climate is changing, largely due to the observed increases in human activities.
- Since 1910 there has been an increase in average surface temperature in Australia of 0.9 degrees Celsius.
- Since 1950, there has been a reduction in cool season rainfall and runoff in southern areas, and an increase in summer rainfall in the north.
- When changes in rainfall are combined with expected increases in potential evaporation, decreases in soil moisture are expected across Australia.
- Extreme rainfall events are projected to increase in intensity.
- Groundwater is vulnerable to climate change and climate variability. Potential climate risks for groundwater include reduced groundwater recharge and groundwater supplies, seawater intrusion to coastal aquifers, reduction of freshwater availability on small islands, and increased demand.
- Increased extreme weather events, such as bushfires and floods, can affect water quality and the infrastructure on which our water resources rely. Increasing temperatures may also increase the risk of bacterial contamination in water supplies, blue-green algal outbreaks and acid-sulphate soil issues.
- More extreme hot days could pose a risk to worker safety and productivity, and disrupt electricity supplies leading to service failure.
- Rising sea levels may pose a flood risk to low-lying coastal assets and may lead to saltwater intrusion into groundwater resources.
- Changes in summer tropical rainfall in northern Australia remain highly uncertain (Source: http://www.environment.gov.au/climate-change/climate-science/climate-change-future/rainfall).

2.3 COMMONWEALTH BUREAU OF METEOROLOGY AND CSIRO REPORTS (CSIRO, 2015A; CSIRO, 2015B)

2.3.1 Overview

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Commonwealth Bureau of Meteorology (BoM) have prepared a report entitled "*Climate Change in Australia Technical Report*" (CSIRO, 2015a). This report provides guidance on the possible projections of future climate for the Monsoonal North based on a current understanding of the climate system, historical trends and model simulations of the climate response to changing greenhouse gas and decreasing aerosol emissions. Projections have been given for a number of climatic variables including (but not limited to) temperature, rainfall, solar radiation, wind speed, cyclones, potential evapotranspiration and sea levels. A second report entitled "*Climate Change in Australia Projections Cluster Report – Monsoonal North*" (CSIRO, 2015b) provides projections for the region where MRM is situated.

2.3.2 Representative Concentration Pathways (RCPs)

It is very difficult to project future anthropogenic greenhouse gas and aerosol emissions because of significant unknowns and uncertainties in population and economic growth, technological developments and transfer, and political and social changes. The climate modelling community has developed Representative Concentration Pathways (RCPs) to explore credible future climate options. The review focused on projections of climatic variables provided for the following range of Representative Concentration Pathway (RCP) scenarios:

- RCP8.5 scenario representing a high emissions scenario with predicted temperature increases of 2.6 to 4.8 degrees Celsius by 2090 compared with 1986 to 2005 conditions. This pathway represents a future with little curbing of emissions, with a CO_2 concentration continuing to rapidly rise, and assumes increases in emissions leading to a CO_2 concentration of about 940 ppm by 2100.
- RCP6.0 scenario representing an intermediate emissions scenario with predicted temperature increases of 1.4 to 3.1 degrees Celsius by 2090 compared with 1986 to 2005 conditions. This pathway represents lower emissions compared to RCP8.5, achieved by application of some mitigation strategies and technologies. This scenario results in the CO_2 concentration rising less rapidly than RCP8.5, but still reaching 660 ppm by 2100.
- RCP4.5 scenario representing an intermediate emissions scenario with predicted temperature increases of 1.1 to 2.6 degrees Celsius by 2090 compared with 1986 to 2005 conditions. This pathway requires slower emission reductions that stabilise the CO_2 concentration at about 540 ppm by 2100. RCP4.5 concentrations are slightly above those of RCP6.0 until after mid-century, but emissions peak earlier (around 2040), and the CO_2 concentration reaches 540 ppm by 2100.
- RCP2.6 scenario representing a low emissions scenario with predicted temperature increases of 0.3 to 1.7 degrees Celsius by 2090 compared with 1986 to 2005 conditions. This pathway requires very strong emission reductions from a peak at around 2020), then declining to reach a carbon dioxide (CO_2) concentration at about 420 parts per million (ppm) by 2100.

The above four RCPs represent the distillation of a much larger number of potential futures that have been discussed. These RCPs have been used in the fifth Climate Model Inter-comparison Project (CMIP5) and the latest IPCC Assessment Report (2013) and differ from the Special Report on Emissions Scenarios (SRES) used in the previous Climate Change in Australia (CSIRO and BOM, 2007) projections report and in the IPCC (2007) report. A comparison of CO_2 concentrations and global temperature for the two sets of scenarios is shown in Figure 2.1 and Figure 2.2 respectively. The RCPs represent a wider set of futures than SRES, and now explicitly include the effect of mitigation strategies.

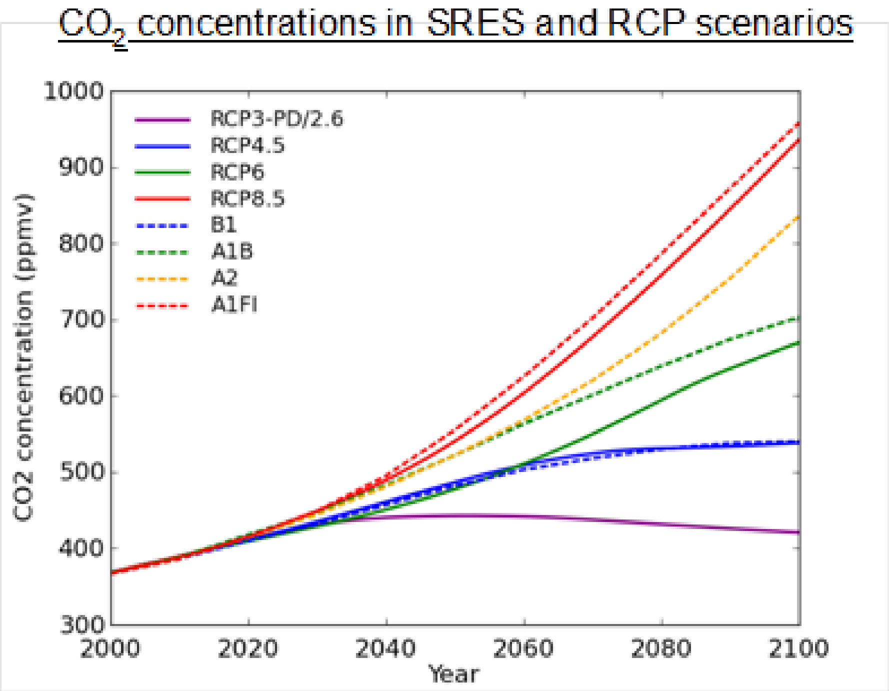

Figure 2.1 Comparison of RCPs and SRESs CO$_2$ concentrations over time (source: CSIRO, 2015a)

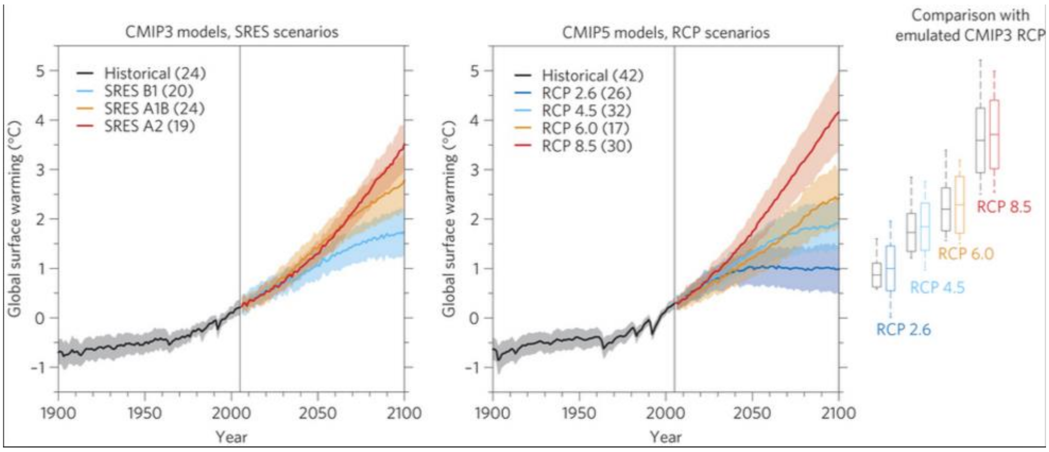

Figure 2.2 Comparison of RCPs and SRESs global temperature over time

Of the above emissions scenarios, RCP4.5 appears to represent the outcomes from the COP21 Paris Agreement.

2.3.3 Findings

For each climate variable, the projected change is accompanied by a confidence rating. This rating follows the method used by the IPCC in the Fifth Assessment Report, whereby the confidence in a projected change is assessed based on the type, amount, quality and consistency of evidence (which can be process understanding, theory, model output, or expert judgement) and the degree of agreement amongst the different lines of evidence (IPCC, 2013). The confidence ratings used here are set as low, medium, high or very high.

The review focuses on climate projections for two time periods:

- Short-term: the 2030 time period (which represents the near future 2020 to 2039).
- Long-term: the 2090 time period (which represents the late in the 21st century 2080 to 2099).

Table 2.1 presents a summary of short-term and long-term climate change findings made in CSIRO (2015a; 2015b) for various climate variables for different emissions scenarios.

Table 2.1 Short-term (near future - 2030) and long-term (late in the century - 2090) climate projections compared to the climate of 1986 to 2005 (source: CSIRO, 2015b)

Climatic Variable	Near future (2030)	Late in the century (2090)
Average temperature	The mean warming is around 0.5 to 1.3 degrees Celsius (projected with very high confidence). Only minor differences projected between different RCPs.	The mean warming is around 1.3 to 2.7 degrees Celsius for RCP4.5 and 2.8 to 5.1 degrees Celsius for RCP8.5.
Average rainfall	There is high confidence that natural climate variability will remain the major driver of annual mean rainfall changes by 2030 (20-year mean differences of +/- 10 % annually). The magnitude of possible summer rainfall change is around +/-10 %. The magnitude of possible differences in spring and autumn rainfall is around -25 % to +20 %.	There is generally low confidence in projected rainfall changes. This is because of the differing simulations of the GCMs, and also because different processes, such as monsoon onset, Madden-Julian Oscillation (MJO) and tropical circulation can have opposite impacts on model projected rainfall changes. Also, there is large spread in the skill of models in simulating these processes. Additionally, GCMs may not adequately represent the influence of Eastern Australian orography on rainfall. The projected change is around -15 % to +10 % under RCP4.5 and around -25 % to +20 % under RCP8.5. There is an indication of a slight decline in spring (model range from around -45 to +30 % under RCP8.5). The magnitude of possible differences in spring and autumn is around +/-30 % under RCP4.5 and -45 to +30 % under RCP8.5
Rainfall intensity	Understanding of physical processes and high model agreement gives high confidence that the intensity of heavy rainfall events (for example, a 5% (1 in 20) annual exceedance probability 1-day rainfall) will increase. The magnitude of change and the time when any change may be evident in addition to natural variability cannot be reliably projected.	Understanding of physical processes and high model agreement gives us high confidence that the intensity of heavy rainfall events will increase. The magnitude of change, and the time when any change may be evident in addition to natural variability cannot be reliably projected.
Drought	There is low confidence in projecting changes in the frequency and duration of extreme meteorological drought.	There is low confidence in projecting changes in the frequency and duration of extreme meteorological drought.

Climatic Variable	Near future (2030)	Late in the century (2090)
Cyclones	Small changes in mean surface wind speed are projected with high confidence under all RCPs. There is medium confidence that tropical cyclones will become less frequent but there will be an increase in the proportion of the most intense storms.	Little change is projected with medium confidence. However, substantial changes are present in some models, seasons and parts of monsoonal north (particularly with increases in spring and decreases in autumn wind speed under RCP8.5). Tropical cyclones are projected with medium confidence to become less frequent, but with increases in the proportion of the most intense storms.
Solar radiation	Little change is projected for solar radiation with high confidence.	Under RCP8.5, larger changes in radiation are projected by some models, and with some agreement on a decrease. The causes of these changes are not well understood and therefore, there is low confidence in these projections.
Relative-humidity	Little change is projected for relative humidity with high confidence.	There is medium confidence in a decrease in relative humidity under RCP8.5 based on model results and physical understanding.
Evapo-transpiration	There is high confidence that potential evapotranspiration will increase in all seasons. However there is only medium confidence in the magnitude of the projected increases.	There is high confidence that potential evapotranspiration will increase in all seasons, with the largest absolute rates in summer by 2090. However, there is only medium confidence in the magnitude of these projections.
Soil moisture	There is medium confidence that soil moisture will decrease predominantly in winter and spring. The changes in soil moisture are strongly influenced by changes in rainfall, but tend to be more negative because they are reinforced by increases in potential evapotranspiration.	The projections indicate overall seasonal decreases with medium confidence, but predominately in winter and spring. The changes in soil moisture are strongly influenced by changes in rainfall, but tend to be more negative because they are reinforced by increases in potential evapotranspiration.
Annual runoff	For reasons similar to soil moisture, runoff is projected to decrease, but only with low confidence. More detailed hydrological modelling is needed to confidently assess changes to runoff.	For reasons similar to soil moisture, runoff is projected to decrease, but only with low confidence. More detailed hydrological modelling is needed to confidently assess changes to runoff.
Sea level	There is very high confidence that sea levels will continue to rise with rise. The projected range of rise is 0.06 m to 0.17 m, with only minor differences between different RCPs.	There is very high confidence that sea level will continue to rise, with projections sensitive to RCPs. By 2090, RCP4.5 gives a rise of 0.28 to 0.64 m and RCP8.5 gives a rise of 0.38 to 0.85 m. These ranges of sea level rise are considered likely (at least 66 % probability). However, if a collapse in the marine based sectors of the Antarctic ice sheet were initiated, these projections could be several tenths of a metre higher by late in the century.

Table 2.2 presents the range of simulated results from Global Climate models (GCMs) for the short-term (2030) and long-term (2090) time periods relative to the climate of 1986 to 2005. The spread of model results are presented (within brackets) as the range between the 10th and 90th percentile. For each time period, the model spread is attributed to three sources of uncertainty: the range of future emissions, the climate response of the models, and natural variability.

Table 2.2 Global climate model simulated changes in Short-term (near future - 2030) and long-term (late in the century - 2090) climate variables relative to the climate of 1986 to 2005 (source: CSIRO, 2015b)

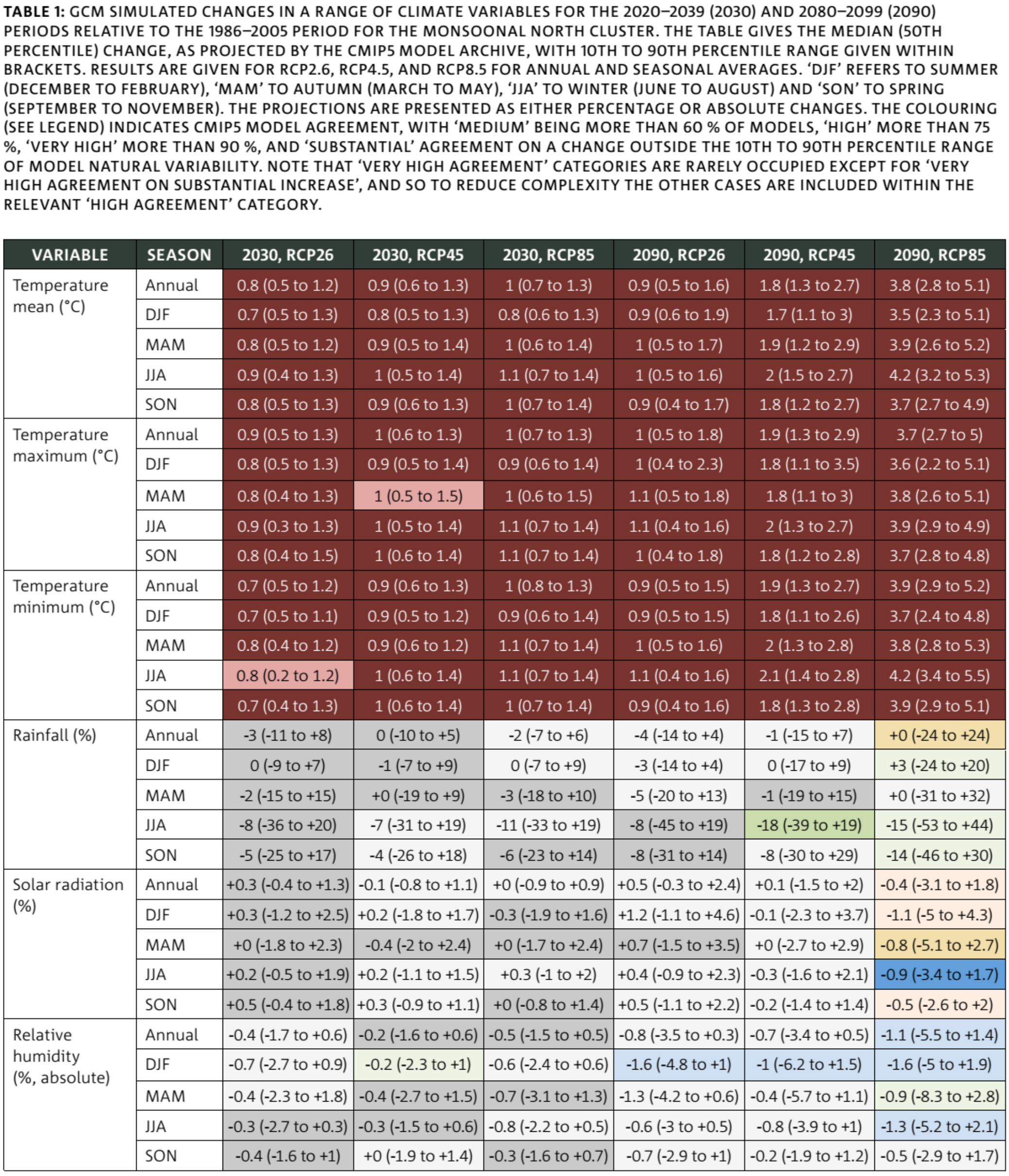

TABLE 1: GCM SIMULATED CHANGES IN A RANGE OF CLIMATE VARIABLES FOR THE 2020–2039 (2030) AND 2080–2099 (2090) PERIODS RELATIVE TO THE 1986–2005 PERIOD FOR THE MONSOONAL NORTH CLUSTER. THE TABLE GIVES THE MEDIAN (50TH PERCENTILE) CHANGE, AS PROJECTED BY THE CMIP5 MODEL ARCHIVE, WITH 10TH TO 90TH PERCENTILE RANGE GIVEN WITHIN BRACKETS. RESULTS ARE GIVEN FOR RCP2.6, RCP4.5, AND RCP8.5 FOR ANNUAL AND SEASONAL AVERAGES. 'DJF' REFERS TO SUMMER (DECEMBER TO FEBRUARY), 'MAM' TO AUTUMN (MARCH TO MAY), 'JJA' TO WINTER (JUNE TO AUGUST) AND 'SON' TO SPRING (SEPTEMBER TO NOVEMBER). THE PROJECTIONS ARE PRESENTED AS EITHER PERCENTAGE OR ABSOLUTE CHANGES. THE COLOURING (SEE LEGEND) INDICATES CMIP5 MODEL AGREEMENT, WITH 'MEDIUM' BEING MORE THAN 60 % OF MODELS, 'HIGH' MORE THAN 75 %, 'VERY HIGH' MORE THAN 90 %, AND 'SUBSTANTIAL' AGREEMENT ON A CHANGE OUTSIDE THE 10TH TO 90TH PERCENTILE RANGE OF MODEL NATURAL VARIABILITY. NOTE THAT 'VERY HIGH AGREEMENT' CATEGORIES ARE RARELY OCCUPIED EXCEPT FOR 'VERY HIGH AGREEMENT ON SUBSTANTIAL INCREASE', AND SO TO REDUCE COMPLEXITY THE OTHER CASES ARE INCLUDED WITHIN THE RELEVANT 'HIGH AGREEMENT' CATEGORY.

VARIABLE	SEASON	2030, RCP26	2030, RCP45	2030, RCP85	2090, RCP26	2090, RCP45	2090, RCP85
Temperature mean (°C)	Annual	0.8 (0.5 to 1.2)	0.9 (0.6 to 1.3)	1 (0.7 to 1.3)	0.9 (0.5 to 1.6)	1.8 (1.3 to 2.7)	3.8 (2.8 to 5.1)
	DJF	0.7 (0.5 to 1.3)	0.8 (0.5 to 1.3)	0.8 (0.6 to 1.3)	0.9 (0.6 to 1.9)	1.7 (1.1 to 3)	3.5 (2.3 to 5.1)
	MAM	0.8 (0.5 to 1.2)	0.9 (0.5 to 1.4)	1 (0.6 to 1.4)	1 (0.5 to 1.7)	1.9 (1.2 to 2.9)	3.9 (2.6 to 5.2)
	JJA	0.9 (0.4 to 1.3)	1 (0.5 to 1.4)	1.1 (0.7 to 1.4)	1 (0.5 to 1.6)	2 (1.5 to 2.7)	4.2 (3.2 to 5.3)
	SON	0.8 (0.5 to 1.3)	0.9 (0.6 to 1.3)	1 (0.7 to 1.4)	0.9 (0.4 to 1.7)	1.8 (1.2 to 2.7)	3.7 (2.7 to 4.9)
Temperature maximum (°C)	Annual	0.9 (0.5 to 1.3)	1 (0.6 to 1.3)	1 (0.7 to 1.3)	1 (0.5 to 1.8)	1.9 (1.3 to 2.9)	3.7 (2.7 to 5)
	DJF	0.8 (0.5 to 1.3)	0.9 (0.5 to 1.4)	0.9 (0.6 to 1.4)	1 (0.4 to 2.3)	1.8 (1.1 to 3.5)	3.6 (2.2 to 5.1)
	MAM	0.8 (0.4 to 1.3)	1 (0.5 to 1.5)	1 (0.6 to 1.5)	1.1 (0.5 to 1.8)	1.8 (1.1 to 3)	3.8 (2.6 to 5.1)
	JJA	0.9 (0.3 to 1.3)	1 (0.5 to 1.4)	1.1 (0.7 to 1.4)	1.1 (0.4 to 1.6)	2 (1.3 to 2.7)	3.9 (2.9 to 4.9)
	SON	0.8 (0.4 to 1.5)	1 (0.6 to 1.4)	1.1 (0.7 to 1.4)	1 (0.4 to 1.8)	1.8 (1.2 to 2.8)	3.7 (2.8 to 4.8)
Temperature minimum (°C)	Annual	0.7 (0.5 to 1.2)	0.9 (0.6 to 1.3)	1 (0.8 to 1.3)	0.9 (0.5 to 1.5)	1.9 (1.3 to 2.7)	3.9 (2.9 to 5.2)
	DJF	0.7 (0.5 to 1.1)	0.9 (0.5 to 1.2)	0.9 (0.6 to 1.4)	0.9 (0.5 to 1.5)	1.8 (1.1 to 2.6)	3.7 (2.4 to 4.8)
	MAM	0.8 (0.4 to 1.2)	0.9 (0.6 to 1.2)	1.1 (0.7 to 1.4)	1 (0.5 to 1.6)	2 (1.3 to 2.8)	3.8 (2.8 to 5.3)
	JJA	0.8 (0.2 to 1.2)	1 (0.6 to 1.4)	1.1 (0.7 to 1.4)	1.1 (0.4 to 1.6)	2.1 (1.4 to 2.8)	4.2 (3.4 to 5.5)
	SON	0.7 (0.4 to 1.3)	1 (0.6 to 1.4)	1 (0.7 to 1.4)	0.9 (0.4 to 1.6)	1.8 (1.3 to 2.8)	3.9 (2.9 to 5.1)
Rainfall (%)	Annual	-3 (-11 to +8)	0 (-10 to +5)	-2 (-7 to +6)	-4 (-14 to +4)	-1 (-15 to +7)	+0 (-24 to +24)
	DJF	0 (-9 to +7)	-1 (-7 to +9)	0 (-7 to +9)	-3 (-14 to +4)	0 (-17 to +9)	+3 (-24 to +20)
	MAM	-2 (-15 to +15)	+0 (-19 to +9)	-3 (-18 to +10)	-5 (-20 to +13)	-1 (-19 to +15)	+0 (-31 to +32)
	JJA	-8 (-36 to +20)	-7 (-31 to +19)	-11 (-33 to +19)	-8 (-45 to +19)	-18 (-39 to +19)	-15 (-53 to +44)
	SON	-5 (-25 to +17)	-4 (-26 to +18)	-6 (-23 to +14)	-8 (-31 to +14)	-8 (-30 to +29)	-14 (-46 to +30)
Solar radiation (%)	Annual	+0.3 (-0.4 to +1.3)	-0.1 (-0.8 to +1.1)	+0 (-0.9 to +0.9)	+0.5 (-0.3 to +2.4)	+0.1 (-1.5 to +2)	-0.4 (-3.1 to +1.8)
	DJF	+0.3 (-1.2 to +2.5)	+0.2 (-1.8 to +1.7)	-0.3 (-1.9 to +1.6)	+1.2 (-1.1 to +4.6)	-0.1 (-2.3 to +3.7)	-1.1 (-5 to +4.3)
	MAM	+0 (-1.8 to +2.3)	-0.4 (-2 to +2.4)	+0 (-1.7 to +2.4)	+0.7 (-1.5 to +3.5)	+0 (-2.7 to +2.9)	-0.8 (-5.1 to +2.7)
	JJA	+0.2 (-0.5 to +1.9)	+0.2 (-1.1 to +1.5)	+0.3 (-1 to +2)	+0.4 (-0.9 to +2.3)	-0.3 (-1.6 to +2.1)	-0.9 (-3.4 to +1.7)
	SON	+0.5 (-0.4 to +1.8)	+0.3 (-0.9 to +1.1)	+0 (-0.8 to +1.4)	+0.5 (-1.1 to +2.2)	-0.2 (-1.4 to +1.4)	-0.5 (-2.6 to +2)
Relative humidity (%, absolute)	Annual	-0.4 (-1.7 to +0.6)	-0.2 (-1.6 to +0.6)	-0.5 (-1.5 to +0.5)	-0.8 (-3.5 to +0.3)	-0.7 (-3.4 to +0.5)	-1.1 (-5.5 to +1.4)
	DJF	-0.7 (-2.7 to +0.9)	-0.2 (-2.3 to +1)	-0.6 (-2.4 to +0.6)	-1.6 (-4.8 to +1)	-1 (-6.2 to +1.5)	-1.6 (-5 to +1.9)
	MAM	-0.4 (-2.3 to +1.8)	-0.4 (-2.7 to +1.5)	-0.7 (-3.1 to +1.3)	-1.3 (-4.2 to +0.6)	-0.4 (-5.7 to +1.1)	-0.9 (-8.3 to +2.8)
	JJA	-0.3 (-2.7 to +0.3)	-0.3 (-1.5 to +0.6)	-0.8 (-2.2 to +0.5)	-0.6 (-3 to +0.5)	-0.8 (-3.9 to +1)	-1.3 (-5.2 to +2.1)
	SON	-0.4 (-1.6 to +1)	+0 (-1.9 to +1.4)	-0.3 (-1.6 to +0.7)	-0.7 (-2.9 to +1)	-0.2 (-1.9 to +1.2)	-0.5 (-2.9 to +1.7)

VARIABLE	SEASON	2030, RCP26	2030, RCP45	2030, RCP85	2090, RCP26	2090, RCP45	2090, RCP85
Evapo-transpiration (%)	Annual	2.5 (1.4 to 3.7)	2.9 (1.6 to 4.3)	3.1 (2.3 to 5.1)	3.4 (2.1 to 6)	6.5 (3.9 to 8.6)	12.4 (8.3 to 16.7)
	DJF	2.6 (1.2 to 4.4)	3.2 (0.6 to 4.4)	3 (1 to 5.4)	4.3 (2.7 to 6.8)	5.8 (2 to 9.4)	11.5 (3.1 to 15.7)
	MAM	2.3 (1 to 4)	2.4 (1.5 to 4.3)	3.3 (2 to 5.7)	3.1 (0.7 to 5.7)	5.9 (4 to 10.3)	12.6 (9.2 to 19.7)
	JJA	2.6 (1.2 to 3.8)	3.3 (1 to 5.4)	3.7 (1.2 to 5.6)	3.3 (0.8 to 6.9)	7.3 (4.7 to 9.4)	15.3 (8.4 to 19.5)
	SON	2.7 (1 to 4.7)	3.1 (1.7 to 5)	3.3 (2 to 4.8)	3.4 (1.5 to 4.7)	6.2 (4.2 to 7.9)	11.7 (8.5 to 16.2)
Soil moisture (Budyko) (%)	Annual	NA	-0.7 (-3.7 to +3.3)	-0.8 (-3.6 to +1.8)	NA	-0.9 (-7.6 to +1.4)	-2.6 (-13.1 to +4)
	DJF	NA	-0.6 (-5.7 to +5.4)	-0.2 (-5.5 to +3.6)	NA	-0.6 (-13.9 to +4.2)	-1.9 (-22.4 to +7.1)
	MAM	NA	-1.1 (-8.1 to +5.5)	-1.6 (-7.1 to +4.9)	NA	-1.9 (-10.3 to +1.5)	-5.4 (-20.8 to +3.9)
	JJA	NA	-0.2 (-3.3 to +2)	-0.3 (-2.1 to +1.3)	NA	-0.7 (-4.8 to +0.3)	-1.5 (-6.3 to +0.8)
	SON	NA	-0.2 (-1.3 to +0.6)	-0.1 (-1.1 to +0.7)	NA	-0.1 (-1.4 to +1.7)	-0.1 (-3.8 to +4.9)
Wind speed (%)	Annual	0.5 (-1.2 to 2)	-0.1 (-2.4 to 0.7)	0.2 (-0.9 to 1.4)	1.1 (-1.7 to 4.9)	-0.4 (-3.4 to 2.6)	0.8 (-3.7 to 5.1)
	DJF	0.2 (-2.4 to 4.7)	0 (-3.7 to 2.6)	1 (-1.1 to 2.8)	1.6 (-1.7 to 6)	0 (-3.3 to 4.6)	1.9 (-3.9 to 8.3)
	MAM	-0.2 (-2.6 to 1.7)	-0.6 (-3.4 to 1.7)	-0.6 (-2.9 to 1)	1.1 (-3.4 to 4.2)	-1.6 (-4.6 to 0.7)	-3.3 (-7.6 to 2.5)
	JJA	0 (-2.7 to 2.9)	-0.3 (-4.2 to 2.7)	-0.2 (-1.5 to 3.1)	0.3 (-1.4 to 5.6)	-0.6 (-5 to 3.8)	0.4 (-2.6 to 6)
	SON	0.9 (-1.2 to 3.3)	0.6 (-2 to 2.6)	0.6 (-1.1 to 2.4)	1.3 (0.1 to 6.6)	1 (-2.7 to 4.9)	2.1 (-0.5 to 8.4)

LEGEND

🟫	Very high model agreement on substantial increase
🟥	High model agreement on substantial increase
🟥	Medium model agreement on substantial increase
🟧	High model agreement on increase
🟧	Medium model agreement on increase
⬜	High model agreement on little change
⬜	Medium model agreement on little change
🟨	Low model agreement on the direction of change
🟦	High model agreement on substantial decrease
🟦	Medium model agreement on substantial decrease
🟩	High model agreement on decrease
🟩	Medium model agreement on decrease

3 Review of historical climate data

3.1 OVERVIEW

The trend in annual rainfall in the Monsoonal North from 1900 to 2012 suggests a slight increase in annual rainfall with alternating decades of wetter and drier conditions throughout the 20th century. The region experienced drier conditions in the early parts of the 20th century that was associated with the Australia-wide Federation drought and the World War II drought. In more recent years, there were more variable rainfall conditions due to the impact of tropical cyclones and strong La Nina events interspersed with sequences of years with dryer than average rainfall in the late 1980's and early 1990's (CSIRO, 2015b).

3.2 COMPARISON OF DATA FOR THE FULL HISTORICAL PERIOD AGAINST THE GLOBAL CLIMATE MODEL REFERENCE PERIOD

Synthetic climate data is available for the MRM site from the Queensland Climate Change Centre of Excellence (QCCCE) SILO Data Drill Service. The MRM Data Drill data have been derived by interpolation of recorded climate data between regional stations as described by Jeffreys et al. (2001). The Data Drill provides a continuous daily data set between 1889 and 2015 (baseline period).

The SILO rainfall data set adopted at MRM has been generated based on three key rainfall stations including MRM (M.I.M. Pump), Borroloola and Anthony Lagoon. A review of recorded rainfalls at these three stations confirm that the adopted MRM SILO data shows similar trends in the annual average rainfalls compared with the recorded rainfalls at MRM, Borroloola and Anthony Lagoon. Hence, the full period of rainfall (1889-2015) has been adopted for use in the project.

Figure 3.1 shows the variation of annual rainfall over baseline period, together with the 10-year annual moving average rainfall over whole period. Table 3.1 and Table 3.2 show the average, median, 10th percentile and 90th percentile climate variables from the SILO data for the 1889 to 2015 historical baseline period and the 1986 to 2005 Global Climate Model reference period respectively. Table 3.3 shows the percentage differences between the average, median, 10th percentile and 90th percentile climate variables from the two data periods.

The comparison of the historical baseline and GCM reference period data sets shows that:

- The average, median, 90th percentile exceedance and 90th percentile exceedance daily temperatures in the GCM reference period are a little higher than the equivalent values for the historical baseline data period.
- The median annual rainfalls in the historical baseline data period and the GCM reference periods are basically the same. However, the average, 10th percentile and 90th percentile values in the historical baseline period are lower than the GCM reference period.
- The average, median and 10th percentile pan evaporation values and median, 10th percentile and 90th percentile evapotranspiration values for the historical baseline period are lower than the equivalent values for the GCM reference period. However, the 90th percentile pan evaporation and average, median and 90th percentile evapotranspiration values for the historical baseline period are higher than the equivalent values for the GCM reference period. This is most likely due to the higher rainfalls experienced in the GCM reference period when compared to the historical baseline period.

- The average, median, 10th percentile and 90th percentile solar radiation values in the historical baseline data period are a little higher than the equivalent values for the GCM reference period.
- The average, median, 10th percentile and 90th percentile vapour pressures in the historical baseline data period are a little lower than the equivalent values for the GCM reference period.

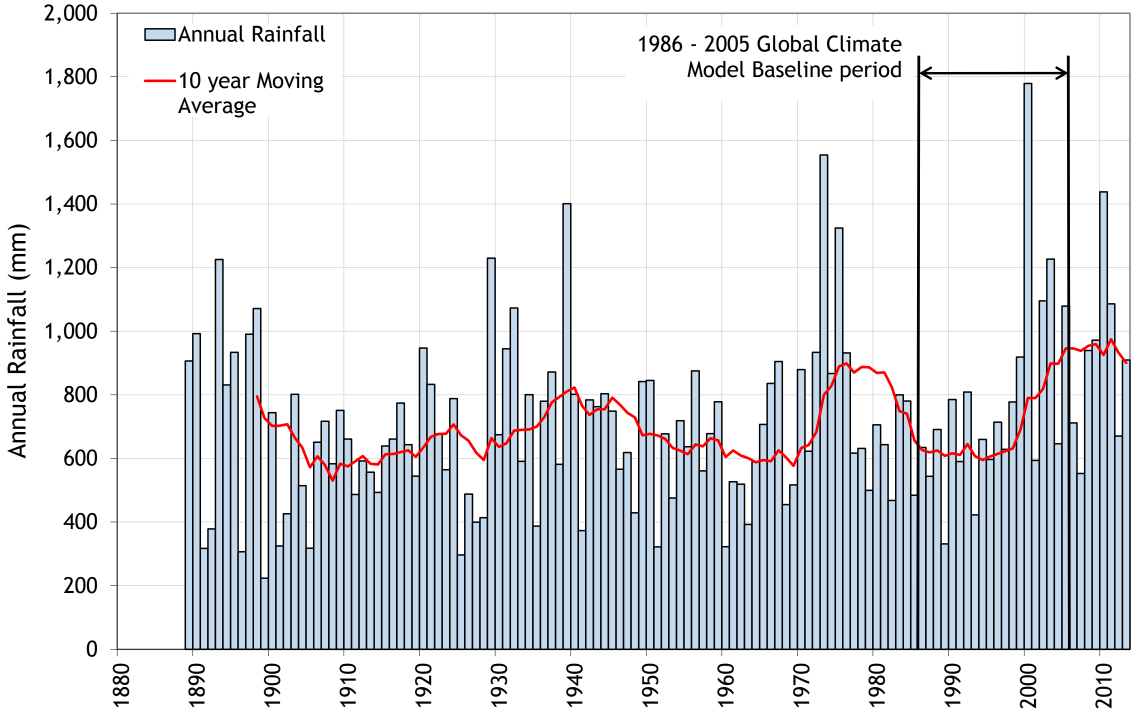

Figure 3.1 - SILO annual rainfall with baseline period

Table 3.1 - Historical (SILO) data statistics - 1889 to 2015 baseline period

	Air Temp Max (˚c)	Air Temp Min (˚c)	Rainfall (mm/a)	Class A Pan Evap (mm/a)	Solar Radiation (MJ/m^2)	Vapour Pressure (hPa)	Evapo-transpiration Morton's Actual (mm/a)
10th Percentile	33.4	18.8	395	2,633	20.1	19.7	911
Average	34.1	19.5	715	2,736	21.0	20.6	1,039
50th Percentile (median)	34.1	19.3	677	2,755	21.1	20.6	1,046
90th Percentile	34.7	20.8	1,040	2,830	22.0	21.4	1,165

Table 3.2 - Historical (SILO) data statistics - 1986 to 2005 GCM reference period

	Air Temp Max (˚c)	Air Temp Min (˚c)	Rainfall (mm/a)	Class A Pan Evap (mm/a)	Solar Radiation (MJ/m^2)	Vapour Pressure (hPa)	Evapo-transpiration Morton's Actual (mm/a)
10th Percentile	33.6	19.1	532	2,436	19.5	20.5	932
Average	34.2	20.3	776	2,709	20.5	21.2	1,023
50th Percentile (median)	34.2	20.4	675	2,740	20.6	21.1	995
90th Percentile	35.1	21.2	1,109	2,920	21.4	22.2	1,143

Table 3.3 - Percentage differences of the historical baseline period when compared with the GCM reference period - SILO Data set

	Air Temp Max (˚c)	Air Temp Min (˚c)	Rainfall (mm/a)	Class A Pan Evap (mm/a)	Solar Radiation (MJ/m^2)	Vapour Pressure (hPa)	Evapo-transpiration Morton's Actual (mm/a)
10th Percentile	-0.5%	-2.0%	-34.6%	7.5%	3.3%	-4.5%	-2.3%
Average	-0.4%	-3.9%	-8.5%	1.0%	2.5%	-3.0%	1.5%
50th Percentile (median)	-0.2%	-5.4%	0.3%	0.6%	2.6%	-2.3%	4.9%
90th Percentile	-1.2%	-1.9%	-6.6%	-3.2%	2.9%	-3.7%	1.9%

4 Assessment approach

4.1 OVERVIEW

The projections for the climate of the Monsoonal North shown in Table 2.2 consider simulated results from a wide range of climate change models. The projections have been viewed in the context of the confidence ratings that are provided, which consider a broader range of evidence than just the model results.

Users from each technical field will identify climate change scenarios of particular relevance to their impact assessment, such as ‘best case’ and ‘worst’ case climate futures. In addition, the users will also identify a ‘maximum consensus’ climate change scenario in which most climate model results reside (CSIRO, 2015b). In other words, the users will identify a subset of three GCM models that can be used to represent their ‘worst’ case, ‘best case’ and ‘maximum consensus’ climate futures.

4.2 BASELINE DATA SET FOR THE EIS PROJECT

The historical baseline data set (1889-2014 SILO dataset) will be used as the baseline data set for climate change impact assessment. Sensitivity analyses (as outlined in Section 4.3) can then be undertaken by rerunning models with same input data, modified to represent ‘best’, ‘worst’ and ‘maximum consensus’ cases as appropriate for different user needs. The reasons for adopting the baseline data set are discussed below.

DoE (2015) and CSIRO (2015a; 2015b) conclude that:

- the projection of annual rainfall change is uncertain and there is high confidence that natural variability will remain the major driver of annual average rainfall in the short-term (2030) compared to the 1986 to 2005 GCM reference period. The level of confidence in projected rainfall for the long-term (2090) is low.
- there is high confidence that potential evapotranspiration will increase in all seasons for both in the short-term (2030) and long-term (2090) time periods. However there is only medium confidence in the magnitude of the projected increases.
- there is high confidence that the intensity of heavy rainfall events (for example, a 5% (1 in 20) annual exceedance probability 1-day rainfall) will increase. The magnitude of change and the time when any change may be evident in addition to natural variability cannot be reliably projected.
- the level of confidence associated with long-term projection for other climate variables such as solar radiation, relative humidity and soil moisture are low or medium.

The comparison of the 1889 to 2015 historical baseline data set with the 1986 to 2005 GCM reference period data set shows that the differences between the median climate values in the historical baseline and GCM reference periods are similar to the differences in the median climate values between projected long-term (2090 RCP4.5 emissions scenario) and GCM reference period values. This includes the projected climate changes for the RCP4.5 emissions scenario, which appears to represent the outcomes from the COP21 Paris Agreement.

4.3 ASSESSING CLIMATE CHANGE IMPACTS

The EIS team members who have to quantify risks associated with climate change impacts may require appropriate data sets for their analyses. There are various approaches available for the creation of such data sets. The choice of approach however should be easy to adopt and commensurate with the intended application of that data, taking into account the degree of uncertainty associated with the dataset. The MRM OMP EIS project will adopt the 'sensitivity analysis' approach for the assessment of climate change impacts.

Sensitivity analysis approach involves running a climate impact model with an observed climate dataset to establish a baseline level of risk, and then rerunning the model with the same input data, modified to represent 'best', 'worst' and 'maximum consensus' cases. This method maintains the relationship between climate variables that are dependent on other dependant and/or independent variables in the GCMs and ensures that spurious relationships between variables are not created that could understate and/or overstate the impacts.

The EIS team members can then compare the historical baseline results with the climate change scenario assessed to determine how sensitive the design is to the scenario assessed and whether the potential impact is adverse, beneficial, or negligible for the design being considered. The EIS team members can then recommend whether or not further design is required to account for this climate scenario.

This approach is effectively used to assess climate change impacts in the water resources and management sectors. This approach is also used in the MRM annual water balance modelling studies and is accepted by the Independent Monitor appointed by the Northern Territory government.

For the purposes of assessing climate change impact for the project, it is proposed to use the following climate change projections:

- During mine operations period (2018 to 2047) the sensitivity assessment is undertaken using the short-term climate change projections.
- For the post operational period (2047 onwards) the sensitivity assessment is undertaken based on the long-term climate change projections.

The adopted approach for assessing the potential risks associated with climate change impacts is considered consistent with the DoE and CSIRO recommendations for assessing climate change risk.

4.4 EXAMPLE PROCEDURE FOR DETERMINING THE CLIMATE DATA FOR CLIMATE CHANGE SENSITIVITY ASSESSMENT

4.4.1 General

An example of how a sensitivity analysis will be undertaken to assess the potential risk of climate change impact on site surface water for (but not necessarily limited to) is given in this section. The example covers:

- short term risks (2018 to 2047) for open pit inundation and mine water dam spills; and
- long term risks (2047 onwards) for final open pit void water quality effects at SW11.

4.4.2 Selection of variables for climate change sensitivity assessments

For each EIS team member the variables used for their sensitivity assessment will depend on the critical climate parameter(s) for the design with respect to their discipline. For example, from a surface water perspective, it is expected that the designs will be most sensitive to changes in rainfall and evapotranspiration rates. The sensitive climate variables for each discipline (e.g., groundwater, geochemistry, final cover design, etc.) will need to be selected by the relevant experts in the particular disciplines.

4.4.3 Proposed method of quantifying climate variable range

The projection builder tool provided in the Climate Change Australia website (http://www.climatechangeinaustralia.gov.au/) will be used to identify the 'worst' case, 'best' case and 'maximum consensus' climate change scenarios by ranking the significance of each climate variable based on the users knowledge of design sensitivity. For example climate variables may be ranked as follows for assessing surface water impacts:

1. Rainfall
2. Evapotranspiration
3. Solar radiation
4. Humidity
5. Wind speed
6. Mean surface temperature

4.4.4 Proposed sensitivity parameters

Table 4.1 shows an example of the results for assessing climate change impacts on surface waters for the best, worst and maximum consensus cases. Table 4.2 and Table 4.3 show the RCP4.5 results from the projections builder for the short term (2030) and long-term (2090) climate projections respectively. The values in Table 4.2 and Table 4.3 will be adjusted to account for the difference between the historical baseline data set (1889 to 2015) and the GCM reference data set (1986 to 2005) given in Table 3.3 (as shown in Table 4.1).

The level of detail considered for the assessment will depend on the EIS team member's knowledge of the system and the tools available. For example, if the magnitude of the projected change is minor or negligible it may be appropriate to undertake a qualitative assessment of the potential impacts. If the magnitude of the projected change is significant or the potential impacts of the interrelated variables are difficult to determine, more detailed modelling may have to be undertaken to assess the impacts.

Table 4.1 Adopted climate change impact sensitivity analysis range example

Case	Annual rainfall	Annual Evapotranspiration	Comments
Short-term assessment			
Best case	-10.2 % minus -8.5 %[1] = **- 1.7 %**	1.5 % minus 1.5 %[1] = **0.0 %**	Representative model: GFDL-ESM2M Consensus: Low
Worst case	6.4 % minus -8.5 %[1] = **14.9 %**	2.8 % minus 1.5 %[1] = **1.3 %**	Representative model: MIROC5 Consensus: Very low
Maximum consensus	0.2 % minus -8.5 %[1] = **8.4 %**	4.4 % minus 1.5 %[1] = **2.9 %**	Representative model: CanESM2 Consensus: High
Projection confidence (from Table 2.1)	High confidence that natural climate variability will remain the major driver of annual mean rainfall changes by 2030 (20-year mean differences of +/- 10 % annually).	There is high confidence that potential evapotranspiration will increase in all seasons. However there is only medium confidence in the magnitude of the projected increases.	
Long-term assessment			
Best case	5.5 % minus -8.5 %[1] = **14.0 %**	5.8 % minus 1.5 %[1] = **4.3 %**	Representative model: GFDL-ESM2M Consensus: Very Low
Worst case	-7.1 % minus -8.5 %[1] = **1.4 %**	2.8 % minus 1.5 %[1] = **1.3 %**	Representative model: MIROC5 Consensus: Low
Maximum consensus	2.7 % minus -8.5 %[1] = **11.2 %**	8.5 % minus 1.5 %[1] = **7.0 %**	Representative model: CanESM2 Consensus: Moderate
Projection confidence (from Table 2.1)	There is generally low confidence in projected rainfall changes. The projected change is around -15 % to +10 % under RCP4.5 and around -25 % to +20 % under RCP8.5. There is an indication of a slight decline in spring (model range from around -45 to +30 % under RCP8.5). The magnitude of possible differences in spring and autumn is around +/-30 % under RCP4.5 and -45 to +30 % under RCP8.5	There is high confidence that potential evapotranspiration will increase in all seasons, with the largest absolute rates in summer by 2090. However, there is only medium confidence in the magnitude of these projections.	

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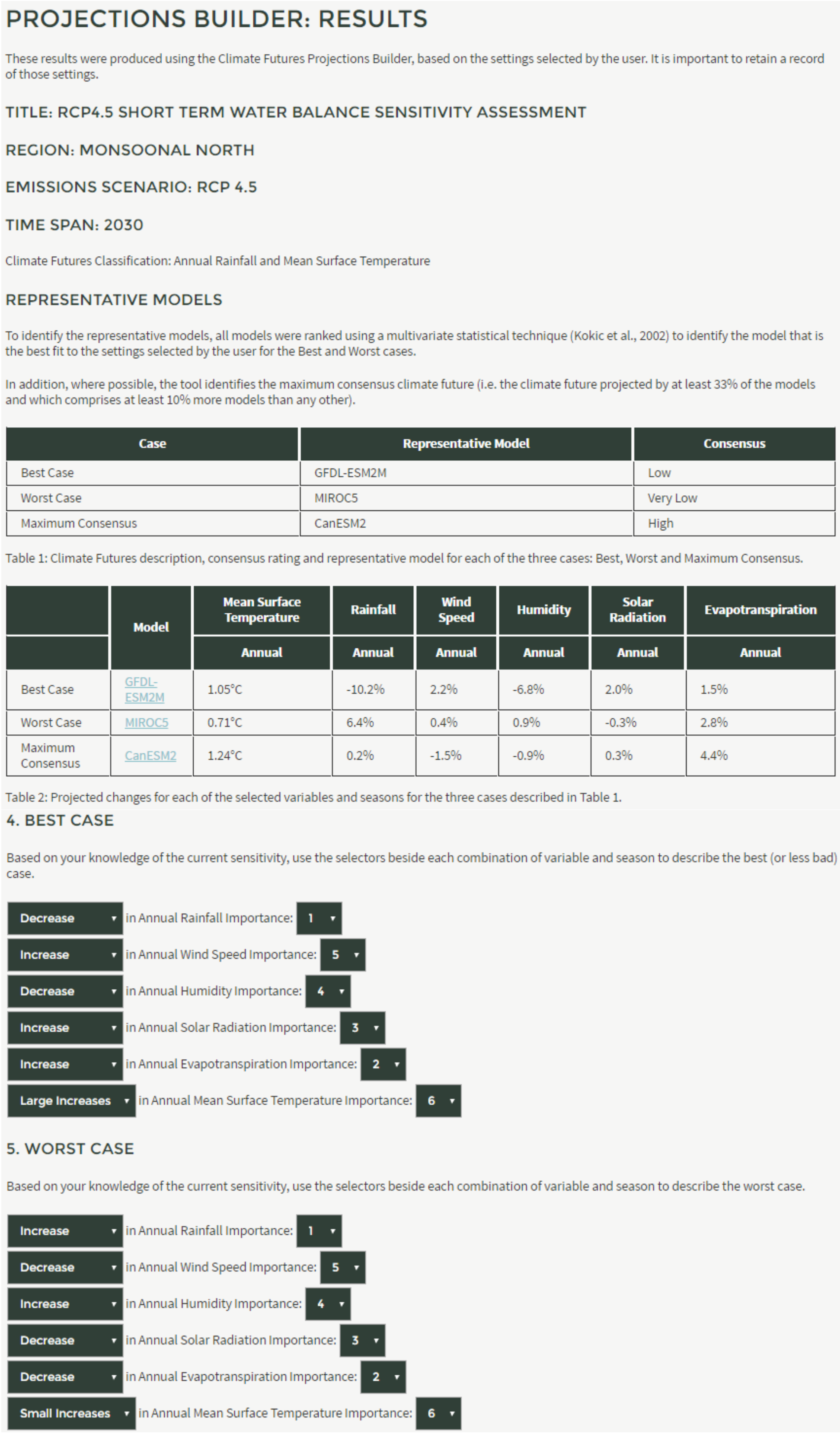
[1] [Climate Change percent difference in Table 4.2 or Table 4.3] minus [average percent difference in Table 3.3]

Table 4.2 Short-term climate projections builder example results (source: CSIRO, 2015b)



PROJECTIONS BUILDER: RESULTS

These results were produced using the Climate Futures Projections Builder, based on the settings selected by the user. It is important to retain a record of those settings.

TITLE: RCP4.5 SHORT TERM WATER BALANCE SENSITIVITY ASSESSMENT

REGION: MONSOONAL NORTH

EMISSIONS SCENARIO: RCP 4.5

TIME SPAN: 2030

Climate Futures Classification: Annual Rainfall and Mean Surface Temperature

REPRESENTATIVE MODELS

To identify the representative models, all models were ranked 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).

Case	Representative Model	Consensus
Best Case	GFDL-ESM2M	Low
Worst Case	MIROC5	Very Low
Maximum Consensus	CanESM2	High

Table 1: Climate Futures description, consensus rating and representative model for each of the three cases: Best, Worst and Maximum Consensus.

	Model	Mean Surface Temperature	Rainfall	Wind Speed	Humidity	Solar Radiation	Evapotranspiration
		Annual	Annual	Annual	Annual	Annual	Annual
Best Case	GFDL-ESM2M	1.05°C	-10.2%	2.2%	-6.8%	2.0%	1.5%
Worst Case	MIROC5	0.71°C	6.4%	0.4%	0.9%	-0.3%	2.8%
Maximum Consensus	CanESM2	1.24°C	0.2%	-1.5%	-0.9%	0.3%	4.4%

Table 2: Projected changes for each of the selected variables and seasons for the three cases described in Table 1.

4. BEST CASE

Based on your knowledge of the current sensitivity, use the selectors beside each combination of variable and season to describe the best (or less bad) case.

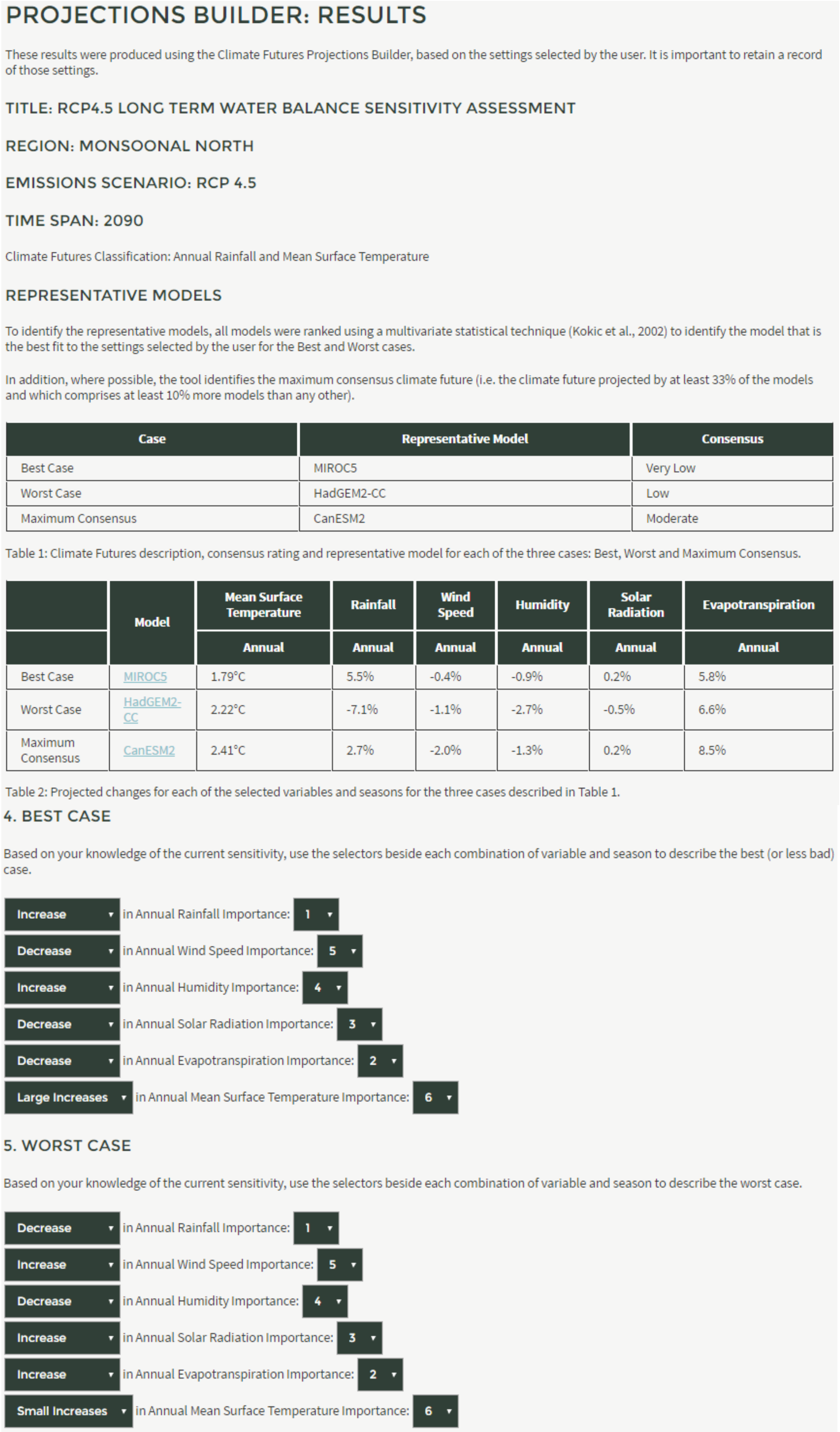
Decrease ▾ in Annual Rainfall Importance: 1 ▾
Increase ▾ in Annual Wind Speed Importance: 5 ▾
Decrease ▾ in Annual Humidity Importance: 4 ▾
Increase ▾ in Annual Solar Radiation Importance: 3 ▾
Increase ▾ in Annual Evapotranspiration Importance: 2 ▾
Large Increases ▾ in Annual Mean Surface Temperature Importance: 6 ▾

5. WORST CASE

Based on your knowledge of the current sensitivity, use the selectors beside each combination of variable and season to describe the worst case.

Increase ▾ in Annual Rainfall Importance: 1 ▾
Decrease ▾ in Annual Wind Speed Importance: 5 ▾
Increase ▾ in Annual Humidity Importance: 4 ▾
Decrease ▾ in Annual Solar Radiation Importance: 3 ▾
Decrease ▾ in Annual Evapotranspiration Importance: 2 ▾
Small Increases ▾ in Annual Mean Surface Temperature Importance: 6 ▾

Table 4.3 Long-term climate projections builder example results (source: CSIRO, 2015b)



PROJECTIONS BUILDER: RESULTS

These results were produced using the Climate Futures Projections Builder, based on the settings selected by the user. It is important to retain a record of those settings.

TITLE: RCP4.5 LONG TERM WATER BALANCE SENSITIVITY ASSESSMENT

REGION: MONSOONAL NORTH

EMISSIONS SCENARIO: RCP 4.5

TIME SPAN: 2090

Climate Futures Classification: Annual Rainfall and Mean Surface Temperature

REPRESENTATIVE MODELS

To identify the representative models, all models were ranked 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).

Case	Representative Model	Consensus
Best Case	MIROC5	Very Low
Worst Case	HadGEM2-CC	Low
Maximum Consensus	CanESM2	Moderate

Table 1: Climate Futures description, consensus rating and representative model for each of the three cases: Best, Worst and Maximum Consensus.

	Model	Mean Surface Temperature	Rainfall	Wind Speed	Humidity	Solar Radiation	Evapotranspiration
		Annual	Annual	Annual	Annual	Annual	Annual
Best Case	MIROC5	1.79°C	5.5%	-0.4%	-0.9%	0.2%	5.8%
Worst Case	HadGEM2-CC	2.22°C	-7.1%	-1.1%	-2.7%	-0.5%	6.6%
Maximum Consensus	CanESM2	2.41°C	2.7%	-2.0%	-1.3%	0.2%	8.5%

Table 2: Projected changes for each of the selected variables and seasons for the three cases described in Table 1.

4. BEST CASE

Based on your knowledge of the current sensitivity, use the selectors beside each combination of variable and season to describe the best (or less bad) case.

Increase ▾ in Annual Rainfall Importance: 1 ▾
Decrease ▾ in Annual Wind Speed Importance: 5 ▾
Increase ▾ in Annual Humidity Importance: 4 ▾
Decrease ▾ in Annual Solar Radiation Importance: 3 ▾
Decrease ▾ in Annual Evapotranspiration Importance: 2 ▾
Large Increases ▾ in Annual Mean Surface Temperature Importance: 6 ▾

5. WORST CASE

Based on your knowledge of the current sensitivity, use the selectors beside each combination of variable and season to describe the worst case.

Decrease ▾ in Annual Rainfall Importance: 1 ▾
Increase ▾ in Annual Wind Speed Importance: 5 ▾
Decrease ▾ in Annual Humidity Importance: 4 ▾
Increase ▾ in Annual Solar Radiation Importance: 3 ▾
Increase ▾ in Annual Evapotranspiration Importance: 2 ▾
Small Increases ▾ in Annual Mean Surface Temperature Importance: 6 ▾

5 References

CSIRO and BOM, 2007	*‘Climate change in Australia: technical report’*, Aspendale, Australia, CSIRO Marine and Atmospheric Research.
CSIRO, 2015a	*‘Climate Change in Australia Information for Australia’s Natural Resource Management Regions: Technical Report’*, CSIRO and Bureau of Meteorology, Australia, 2015
CSIRO, 2015b	*‘Monsoonal North Cluster Report, Climate Change in Australia Projections for Australia’s Natural Resource Management Regions: Cluster Reports’*, eds. Ekström, M. et al., Moise, A. et al., CSIRO and Bureau of Meteorology, Australia, 2015.
DoE, 2015	*‘Commonwealth of Australia, National Climate Resilience and Adaptation Strategy’*, Australian Government Department of Environment, 2015.
IPCC, 2007	*‘Climate Change 2007: The Physical Science basis: Working group I contribution to the Fourth Assessmentreport of the IPCC’*. In: SOLOMON, S. (ed.). Cambridge: Cambridge University Press.
IPCC, 2013	*‘Climate Change 2013: The Physical ScienceBasis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change’*. In: STOCKER, T. F., D. QIN, G.-K.PLATTNER, M. TIGNOR, S. K. ALLEN, J. BOSCHUNG, A.NAUELS, Y. XIA, V. BEX AND P. M. MIDGLEY (ed.).
Jeffreys et al (2001)	*‘Using spatial interpolation to construct a comprehensive archive of Australian climate data’, Jeffrey, S.J., Carter, J.O., Moodie, K.M and Beswick, A.R, Environmental Modelling and Software, Vol 16/4, pp 309-330, 2001.*