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1 Chapter summary

This chapter provides a consolidated reference for the weather and climate-related influences of the Project. Meteorology, hydrology and climate characteristics drive key considerations for numerous phases of the Project, including the design, approvals, construction, operations and revenue modelling. Additional information will be included in the relevant chapters of the report as required.

1.1 Introduction

Snowy Hydro has hydro-meteorological data dating back to the early investigation phase prior to construction of the original Snowy Mountains Scheme (the Scheme). High-quality observations have continued to be recorded through to the present day as part of Snowy Hydro's routine operations. Snowy Hydro's records have been utilised by the Project to identify weather and climate-related operating conditions and potential risks.

1.2 Scope and exclusions

The hydro-meteorological information presented is from Snowy Hydro-operated weather stations and reservoir recordings. Snowy Hydro is fortunate to have two accurate and long-term weather stations close to the proposed Project alignment. This information has been utilised in this chapter. However, due to the changes in elevation across the alignment (approximately 1,000m elevation drop), localised climate variability exists and therefore these can only be used as a guide.

The hydrology section utilises long-term inflow records from Tantangara and Talbingo reservoirs to plot the monthly average inflows. Peak flood levels are also estimated using previous dam safety modelling at both Reservoirs.

The change in climatic conditions section reviews relevant climate change literature and presents a summary of expected regional climate within the operating life (100 years) of the Facilities based on the current state of scientific knowledge.

1.3 Activities undertaken

Hydrology, meteorology and Reservoir inflow data has been updated to include the latest data acquired between the Feasibility Study (December 2017) and FID.

Regulatory and operational water constraint review was undertaken to support market modelling (see *Chapter Five - Market Modelling*).

Wind generation vs water inflow and wind vs solar generation correlation analysis was conducted to assist in understanding future market drivers (see *Chapter Five*).

1.4 Meteorology

Mean monthly temperatures and precipitation for both Tantangara and Talbingo have been determined based on data from Snowy Hydro-operated weather stations and Reservoir recordings. This data has been used to assess design and construction risks.

1.5 Hydrology

Historical monthly inflows at Tantangara and Talbingo reservoirs and an overview of the flood hydrology at each of the Reservoirs were determined. The hydrology information included in this chapter provided the key design flood levels for both reservoirs that were used in the design of the intake structures, for construction and long-term operational use. More information can be found in *Chapter Twelve - Facilities.*

As required by the NSW *Dams Safety Act 2015*,[1] Snowy Hydro as a dam owner is required to undertake flood hydrology assessments of their dams in order to develop and implement a dam emergency plan. Both Tantangara and Talbingo have recently been assessed.

1.6 Future change in climatic conditions in the Snowy Mountains

Global climate is changing, with notable observed changes in Australia and the Snowy Mountains over the last century. Changes are expected to continue and will likely affect future operations of Snowy Hydro.

[1] Available at: https://legislation.nsw.gov.au/acts/2015-26.pdf [Accessed November 15, 2017].

Long-term change in climatic conditions projections for the Project need to be considered in conjunction with historical observations. In summary, the following can be inferred from relevant climate change literature and regional climate projections:

1. **Rising temperature** - Mean, maximum and minimum air temperature are projected to rise by an average of ~2°C (by 2060 - 2079) with an increased frequency of extreme hot days;
2. **Decreasing precipitation** - Generally precipitation is projected to decrease on average, dominated by reduced cool-season precipitation (and snow cover);
3. **Increasing drought** - Drought frequency is projected to increase.
4. **Decreasing inflows** - Long-term inflows and water resources for generation in the Scheme are likely to decrease on average over the next century;
5. **Increased precipitation event intensity** - Precipitation events are projected to become more intense. More extreme flood events present increased physical risks to Scheme infrastructure and operations; and
6. **Increasing bushfire risk** - The bushfire risk in the Snowy Mountains and the general region of the National Energy Market (***NEM***) is expected to increase with the projected warmer and drier climate.

Potential changes in climate over the next century will be considered in the Project design to ensure infrastructure is resilient to future change. As the proposed Facilities will be utilising existing water storages of Tantangara Reservoir for generation and then discharging into Talbingo Reservoir before pumping the utilised water back to Tantangara, there is no additional water required. The Facilities' ability to recycle available water via pumped storage will be critical during periods of lower inflow and drought. Further information on water management can be found in *Chapter Eleven - Environment, Permits & Approvals*.

2 Activities undertaken

The hydrology, meteorology and reservoir inflow data presented in the Feasibility stage has been updated to include the most currently available data. As noted later in this chapter, data collected by Snowy Hydro is of very high quality, and the latest updates help to strengthen the assumptions throughout the FID report that are based on this data.

Constraints on the operation of the Scheme and the Project enforced through the Snowy Water Licence and based on the meteorology, hydrology and change in climatic conditions assessments in this chapter, were reviewed and refined for *Chapter Five - Market Modelling.* These activities were carried out to ensure that these regulatory and operational constraints were thoroughly understood and appropriately represented by the models being used to assess the commercial aspects of the Project. Their inclusion in the market modelling further strengthens the robustness of this process.

3 Meteorology

3.1 Overview

The information in this section is from Snowy Hydro-operated automatic weather stations (***AWS***):

1. For Tantangara, observations are recorded at the Tantangara weather station, located at the southern end of the reservoir. This site has intermittent records as far back as 1969, but good quality continuous records began in 1993. The site is at a relatively high-elevation location within the Kosciuszko National Park (***KNP***) at 1,237 m above sea level; and
2. For Talbingo, conditions near Talbingo Reservoir may be characterised by observations recorded at the Talbingo weather station. This station (which has operated since 1993) is located close to the township of Talbingo at the northern end of the Talbingo Reservoir, at an elevation of 396 m above sea level and outside the boundary of KNP.

3.2 Ambient temperature

3.2.1 Tantangara

Mean monthly maximum temperatures range from 7.0˚C in July to 23.3˚C in January. The highest January temperature on record is 34.4˚C and the lowest temperature on record is -14.9˚C. Mean monthly minimum (overnight) temperatures range from -3.9˚C in July to 6.5˚C in January.

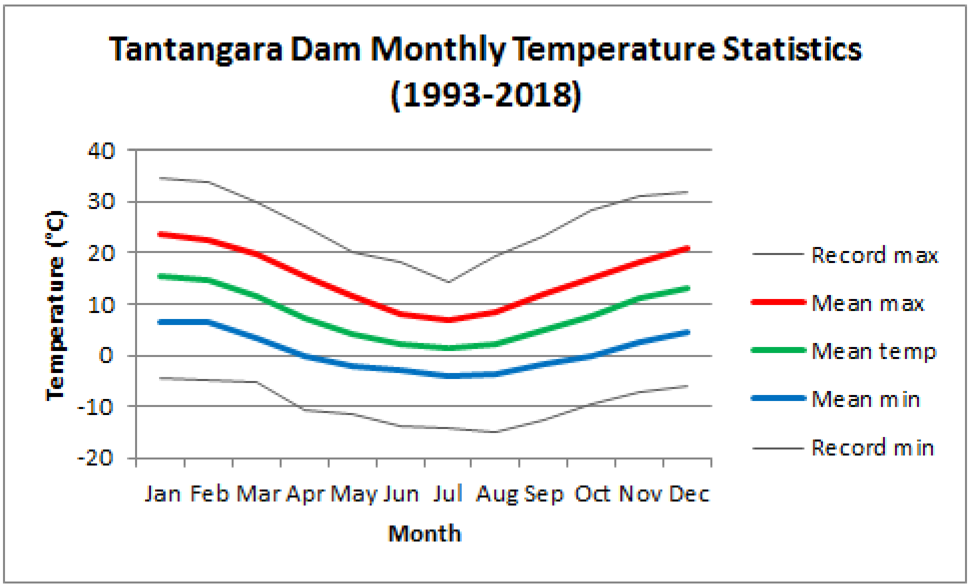

Figure 1: Ambient air temperature at Tantangara Reservoir AWS

3.2.2 Talbingo

Mean monthly maximum temperatures range from 12.5˚C in July to 30.3˚C in January. The highest January temperature on record is 42.2˚C and the lowest on record is -3.3ºC in August. Mean monthly minimum (overnight) temperatures range from 3.0˚C in July to 15.3˚C in January.

These temperatures must be adjusted slightly when considering the proposed Ravine option power station complex. The access site in Lobs Hole Ravine is ~200 m higher than Talbingo, which would translate to about a degree lower temperatures on average. The Ravine location is at the bottom of a valley which may result in enhanced cold air drainage overnight, which could bring minimum temperatures a further degree or so below Talbingo temperatures.

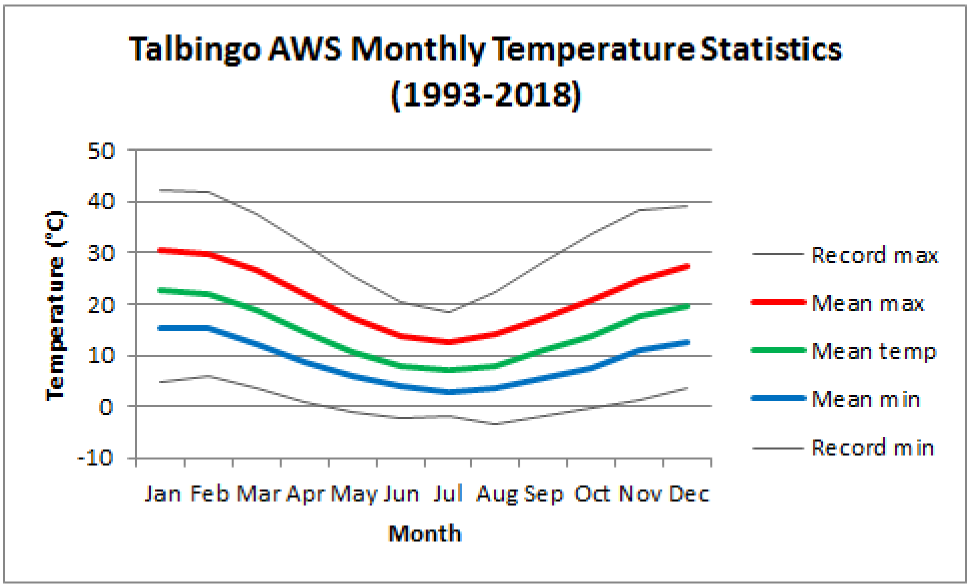

Figure 2: Ambient air temperature at Talbingo AWS

3.3 Precipitation

3.3.1 Tantangara

Tantangara receives average annual total precipitation of ~988 mm, but the year-to year variability can be large. The heaviest precipitation occurs during the winter/spring months (June - October). Precipitation regularly falls as snow during winter, and given the temperature climatology some snowpack should be expected during the coldest months, although it is unlikely to persist at significant depth for long periods.

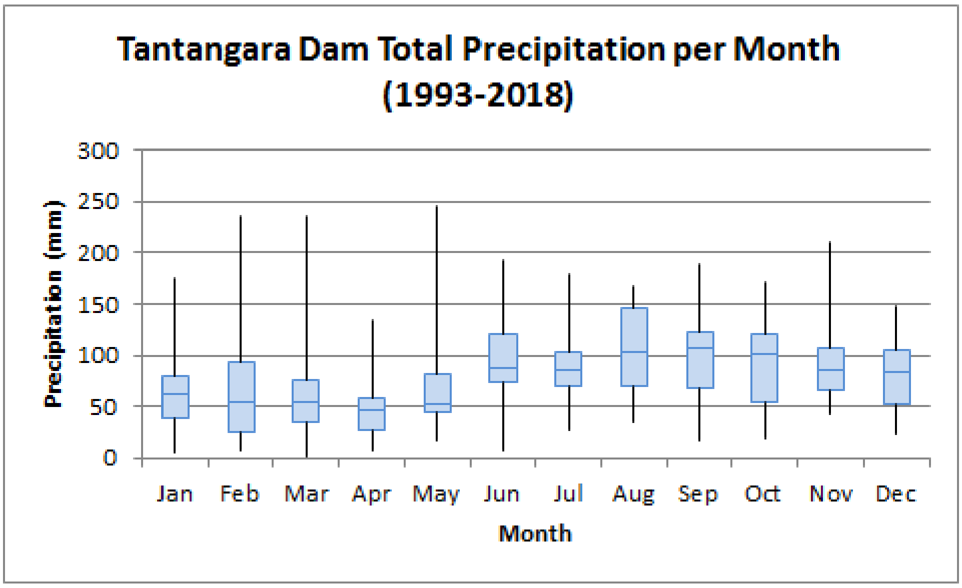

Figure 3: Monthly precipitation at Tantangara Reservoir AWS

3.3.2 Talbingo

Talbingo receives an annual total precipitation amount of ~980 mm per year, but again there can be substantial year-to-year variability. The wettest months of the year are typically late autumn to early spring (May - September). Snowfall at Talbingo and Ravine would be a relatively rare occurrence (<1 per year at Talbingo, 1-2 times per year at Ravine), and would not remain on the ground for any appreciable length of time.

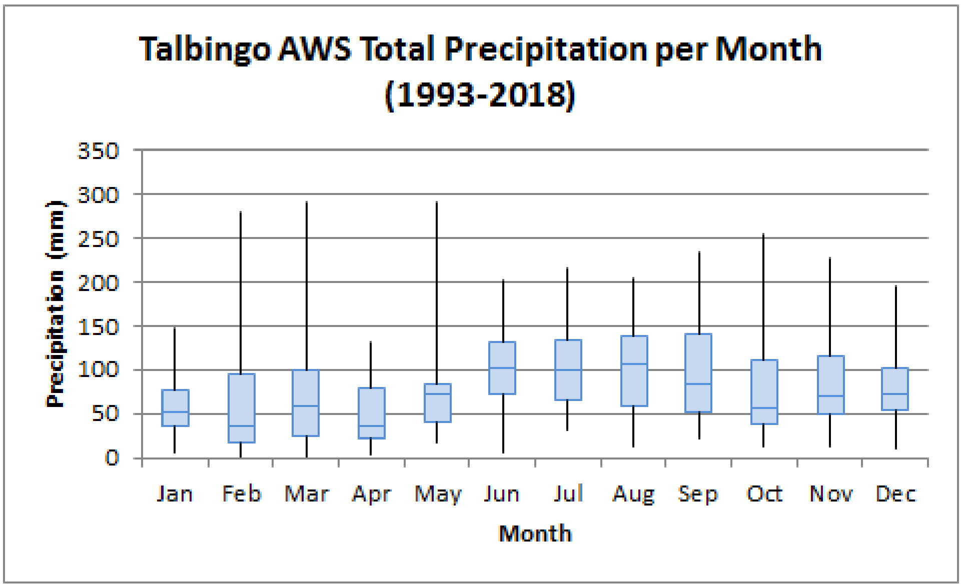

Figure 4: Monthly precipitation at Talbingo AWS

4 Hydrology

4.1 Overview

Information in this section is derived from inflow measurements taken across the Snowy Mountains scheme. Inflow statistics for all reservoirs in the Snowy Mountains Scheme, including Tantangara and Talbingo have been recorded since investigations for the scheme commenced (1953 for Tantangara and 1948 for Talbingo). During the investigations and subsequent operations, an inflow record was also developed between 1905 and the beginning of measured records based on parametric regressions with nearby gauged catchments. The inflow record from 1905 to present is considered applicable and robust for all retrospective hydrological assessments of the Scheme.

4.2 Inflows

4.2.1 Tantangara

Tantangara Reservoir receives 297 GL of inflow per year, but is subject to substantial year-to-year variability, with annual inflows ranging between 36 GL in 2006/2007 and 714 GL in 1917/1918. The highest inflows typically occur between July and October as the accumulated winter snow melts and localised precipitation peaks.

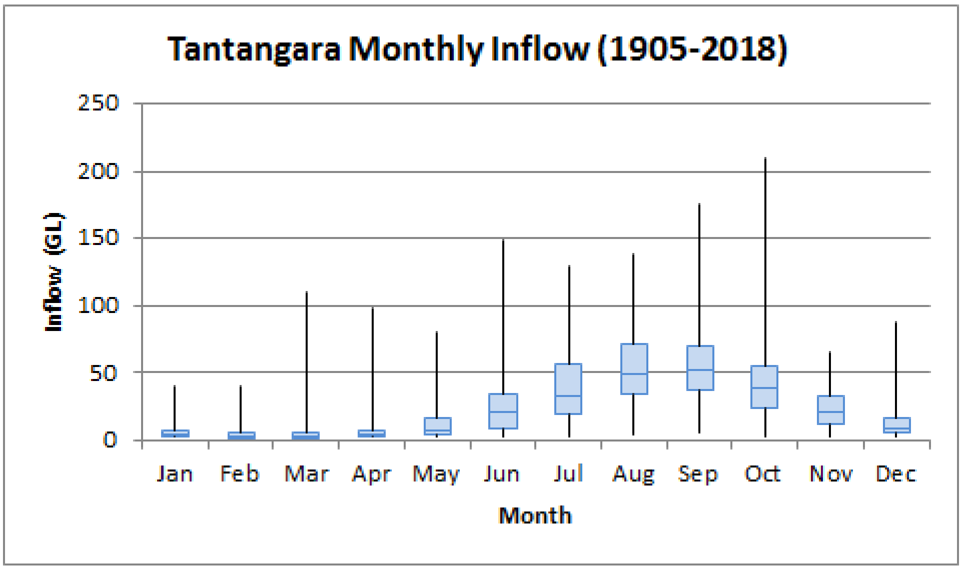

Figure 5: Monthly inflows at Tantangara Reservoir

4.2.2 Talbingo

Talbingo Reservoir receives 330 GL of inflow per year but is subject to substantial year-to-year variability, with annual inflows ranging between 30 GL in 2006/2007 and 820 GL in 1956/1957. The highest inflows occur between July and October as the accumulated winter snow melts in the upper parts of the catchment and localised precipitation peaks. Inflows vary noticeably to the precipitation record at

Talbingo Dam as a lot of the catchment is at higher elevations and is subject to different precipitation patterns.

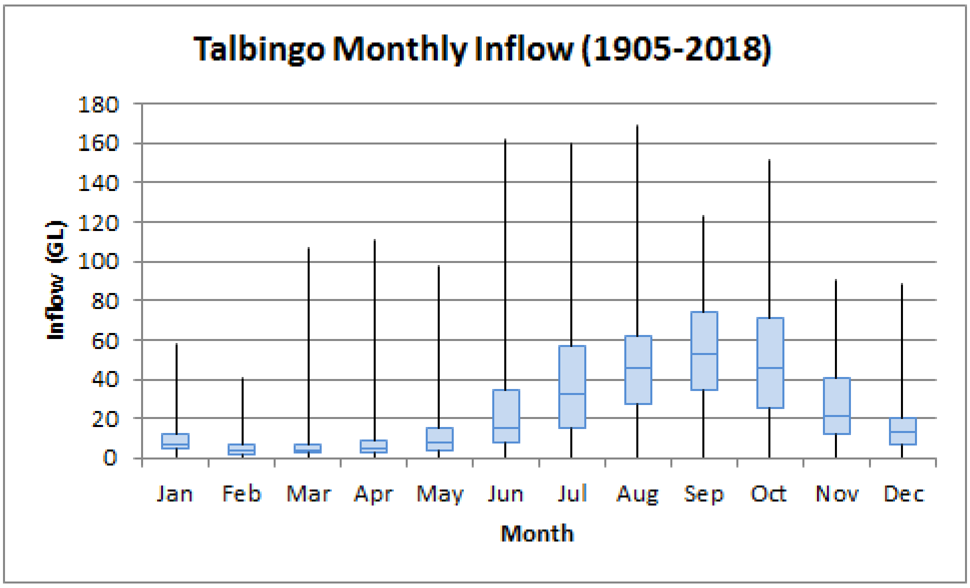

Figure 6: Monthly inflows at Talbingo Reservoir

4.3 Flood Hydrology

As required by the *Dams Safety Act 2015*, Snowy Hydro as a dam owner is required to undertake flood hydrology assessments of their dams in order to develop and implement a dam emergency plan. Both Tantangara and Talbingo were assessed, in 2015 by Jacobs Australia Ltd (Jacobs), and in 2011 by Sinclair Knight Merz (now Jacobs) respectively. See the *Supporting information* for this chapter.

Table 1 below outlines the peak Reservoir levels determined from the analysis. The location of both Tantangara and Talbingo intakes have been designed to withstand a 1% AEP flood without the need of a cofferdam. Further information can be found in *Chapter Twelve - Facilities*.

Event probability - Annual Exceedance Probability (*AEP*)	Peak Reservoir elevation [m Australian Height Datum (AHD)]	
	Tantangara Reservoir	**Talbingo Reservoir**
20%	1,222.13	543.03
10%	1,224.13	543.12
5%	1,225.63	543.13
2%	1,230.10	545.97
1%	1,230.33	546.11
0.5%	1,230.58	546.44
0.2%	1,230.94	546.97
Dam crest flood (~ 0.001% AEP)	1,233.87	550.51

Table 1: Peak Reservoir elevation levels in Tantangara and Talbingo Reservoirs

The dam modelling undertaken uses a conditional probability approach which assumes drawdown is occurring within the Reservoirs before the flood event commences. The risk profile of Talbingo Reservoir is sensitive to the assumed average water level within Talbingo, as the capacity of the Talbingo spillway is constrained. If there is a material long-term change in the operation of Talbingo, the risk profile will change based on the extent of the average water level change. In regards to Tantangara, the risk profile is not sensitive to water level, however, the maintenance requirements are. Increasing the water level for example at Tantangara, will increase the inspection frequency requirements.

The Facilities will be operated by pumping of water for storage when available energy supply is greater than system demand, and then generating with this stored water for short periods when required. It is anticipated this will result in Tantangara Reservoir generally operating at slightly higher average levels, and Talbingo Reservoir generally operating at lower or average levels. The post feasibility analysis will identify improved storage operation protocols to optimise generation and pumping capability concurrently with spill risks. Dam safety protocols will be updated as required to the extent that they are impacted by changed operation of the storages.

5 Future change in climatic conditions in the Snowy Mountains

5.1 Introduction

Global climate is changing, with notable observed changes in Australia and the Snowy Mountains over the last century. Changes are expected to continue and will likely affect future operations of Snowy Hydro. It is therefore important to incorporate consideration of change in climatic conditions in long-term planning of Snowy Hydro infrastructure and business operations to reduce risk and build resilience to likely, yet uncertain future changes.

This section summarises relevant climate change literature and regional climate projections and presents a summary of expected regional climate within the operating life (100 years) of the Project based on the current state of scientific knowledge. Climate projections presented here focus on the NSW and ACT Regional Climate Modelling (***NARCliM***) Project which uses a 'business-as-usual' high emission scenario to which emissions are currently most closely tracking.[2] More moderate emission scenarios and climate projections are available that consider various greenhouse gas reduction and global mitigation measures through the next century. The high emission climate projections are used to demonstrate the climate risk to which Snowy Hydro is exposed.

5.2 Temperature

Temperature projections are a highly robust output from climate models with very high agreement between different climate models. The NARCliM temperature projections for 2060-2079 in Figure 7 and Figure 8 show that widespread warming is expected with an increase in warm extremes and a decrease in cold extremes. These results are consistent with observed trends and climate modelling by other climate modelling projects.

Based on the NARCliM 10 km grid cell near Tantangara (and throughout the region), mean temperature is projected to rise by ~2.1°C by 2060 - 2079 while average maximum temperature rises by ~2.3°C and average minimum temperature rises by ~2.0°C. The spread in the NARCliM climate models is generally between 1.5 and 3°C (Table 2). For later in the century (~2090), CSIRO/BoM climate projections show mean warming across the Murray Basin to be 2.7 - 4.5°C under a high emissions scenario.[3] Mean summer maximum temperatures are up to 5.1°C warmer than the 1986 - 2005 average (Table 3).

The projected changes in temperature extremes are sensitive to local climatological factors such as site location and elevation. In the Talbingo area, the number of hot days >35°C in NARCliM are projected to increase by more than 12.9 days per year by 2060 - 2079, however, at the typically cooler higher elevation areas around Tantangara, the increase in hot days >35°C is projected to be 0.4 days per year. By 2060 - 2079 the number of cold nights (min temperature < 2°C) is projected to reduce by ~47 days per year around Tantangara and ~43 days per year around Talbingo. Frost days are projected to decrease while extended periods of extreme heat (heatwaves) are projected to increase in frequency, length and intensity.

[2] (NSW Government Environment & Heritage).
[3] (Timbal 2015).

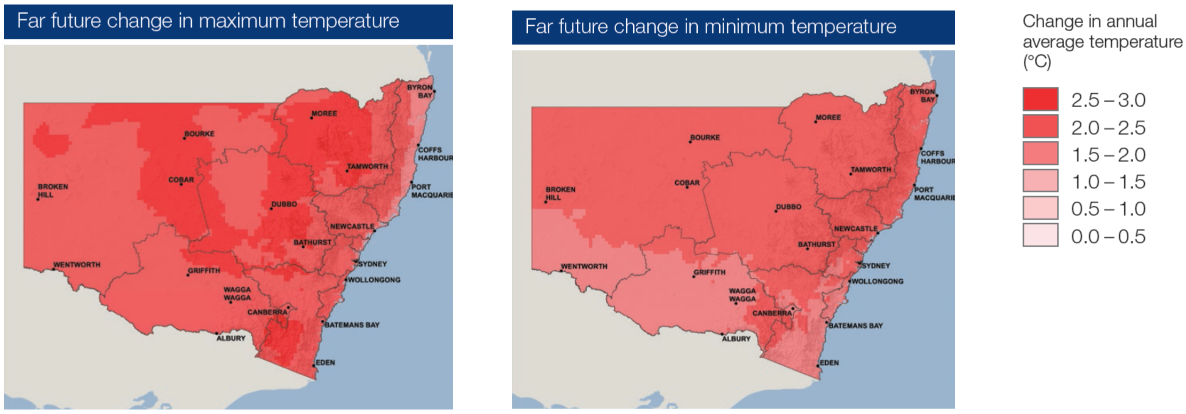

Figure 7: NARCliM change in annual mean temperature by 2060-2079[4]

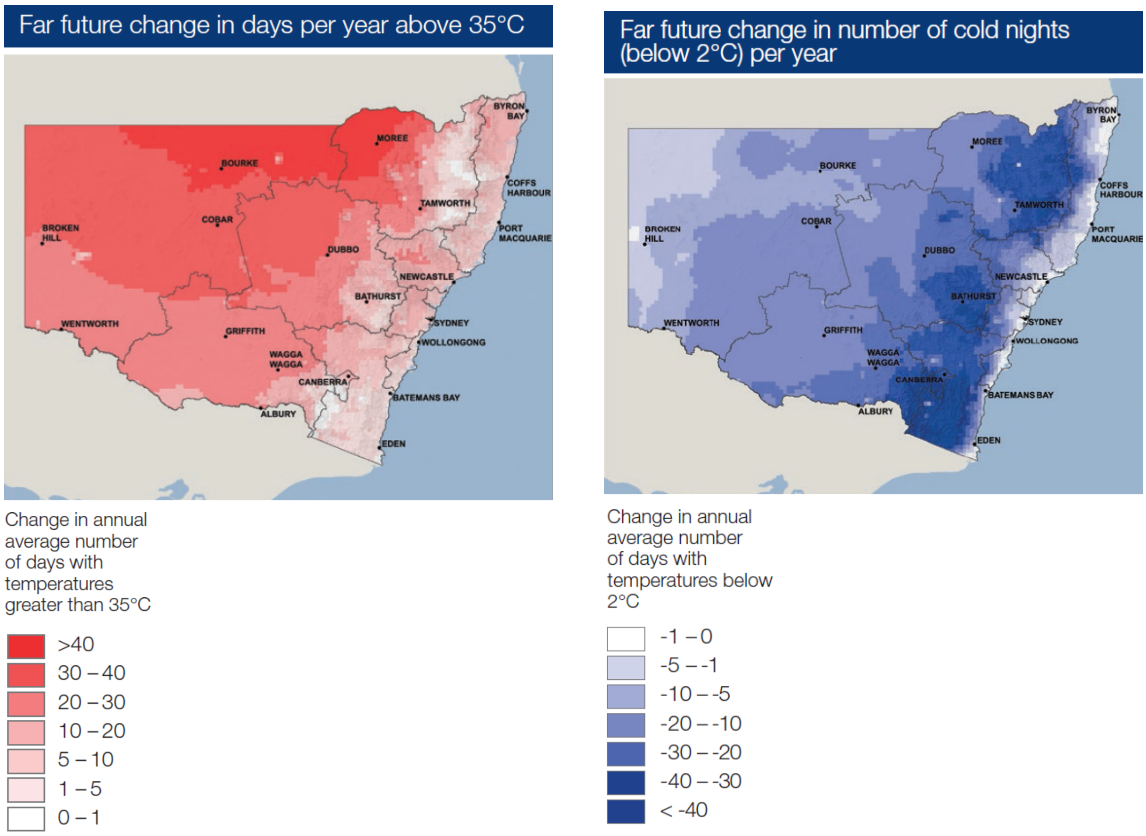

Figure 8: NARCliM change in temperature extremes by 2060-2079[5]

[4] NARCliiM Change in annual mean daily maximum and minimum temperature by 2060-2079 compared to 1990-2009 baseline.

[5] NARCliM change in temperature extremes number of days >35°C (top) and number of cold nights <2°C (bottom) by 2060-2079 compared to 1990-2009 baseline.

	Annual	Summer	Autumn	Winter	Spring
Mean temperature	1.6 - 2.5	1.9 - 3.0	1.5 - 2.6	1.1 - 2.0	1.8 - 2.8
Max temperature	1.8 - 2.6	1.8 - 3.0	1.6 - 2.4	0.9 - 2.0	2.0 - 3.2
Min temperature	1.4 - 2.6	1.8 - 3.2	1.3 - 3.0	1.1 - 2.2	1.5 - 2.5

Table 2: Range of temperature change by 2060-2079[6]

	Annual	Summer	Autumn	Winter	Spring
Mean temperature	2.7 - 4.5	2.7 - 5.4	2.8 - 4.7	2.6 - 3.8	2.9 - 4.8
Max temperature	2.9 - 5.0	2.9 - 5.1	2.7 - 4.9	2.8 - 4.5	3.1 - 5.8
Min temperature	2.8 - 4.2	2.8 - 5.0	2.9 - 4.6	2.3 - 3.6	2.7 - 4.2

Table 3: 10th and 90th percentile range of temperature change by 2080-2099[7]

5.3 Precipitation

Precipitation is more difficult to predict in global climate models due to the highly variable and dynamic processes that drive precipitation patterns. As such, uncertainty remains on the impact of change in climatic conditions on water resources in the Snowy Mountains. Notwithstanding this uncertainty, the general consensus is that cool-season (winter-spring) rainfall is expected to decrease whereas warm-season (autumn-summer) rainfall is projected by the majority of models to remain unchanged or increase across southern Australia and NSW (Figure 9; Table 4).

NARCliM modelling suggests that mean annual precipitation in the Snowy Mountains region may decline by up to -9% by 2060 - 2079, dominated by winter-spring decline (-15 - 20%). For later in the century (~2090), CSIRO/BoM climate projections show that Murray Darling Basin cool-season precipitation changes span -48 to +6% (Table 8).

Despite the decline in precipitation, more extreme rainfall events are expected. As temperatures rise, the atmosphere is able to hold more water, increasing the possibility of extreme rainfall and flash flooding.[8] CSIRO/BoM climate projections show that the magnitude of maximum daily rainfall could increase by up to ~30% by 2080 - 2099.

[6] In the individual 12 NARCliM climate models across NSW.
[7] (Timbal 2015) In CSIRO/BoM climate projections for the Murray Basin.
[8] (Bao et al. 2017).

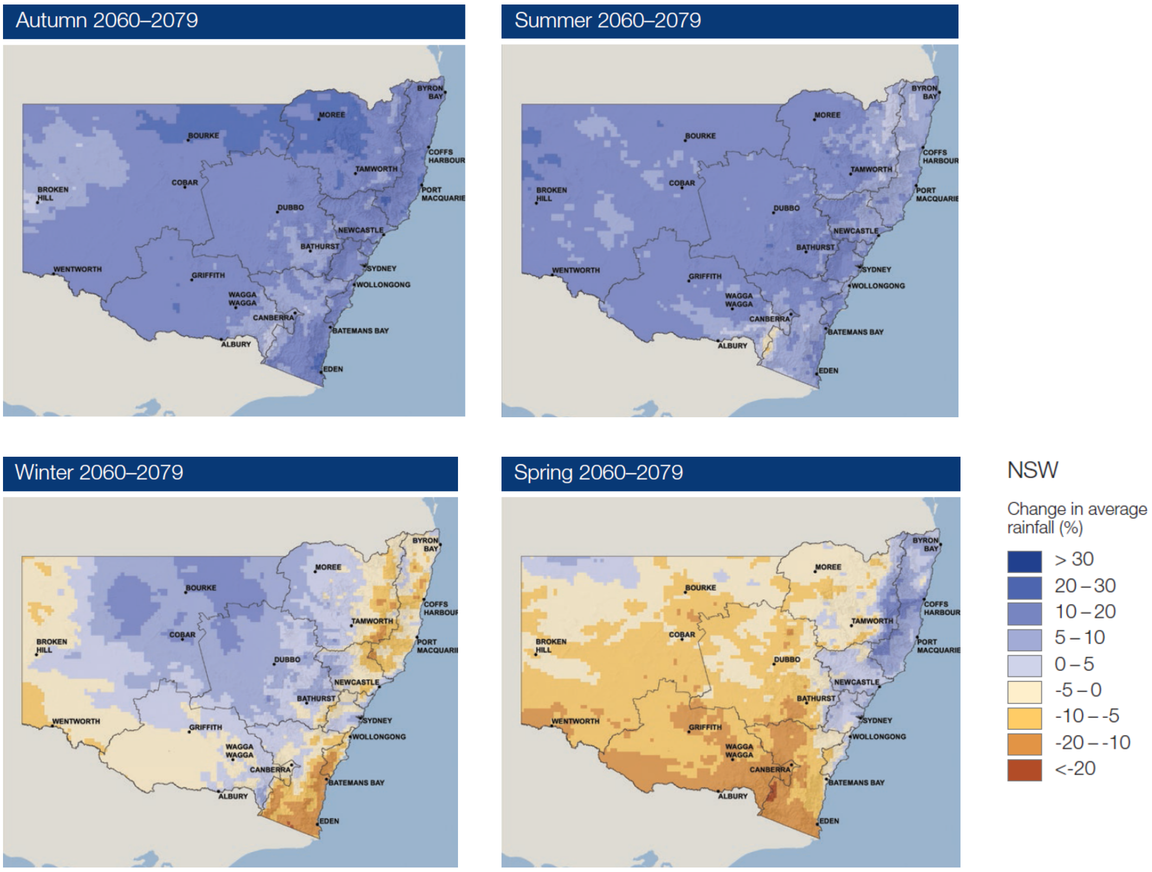

Figure 9: NARCliM projected changes in mean rainfall by season[9]

	Annual	Summer	Autumn	Winter	Spring
Rainfall NSW	-7.6 to +20.3	-4.0 to +34.8	-6.9 to +53.8	-24.7 to +23.5	-17.9 to +14.4
Rainfall Murray Murrumbidge e	-7.6 to +16.1	-7.3 to +28.4	-4.5 to +68.5	-17.7 to +16.3	-18.6 to -7.5
Rainfall SE Tablelands	-6.4 to +9.9	-7.8 to +32.7	-6.4 to +44.6	-20.4 to +11.2	-20.4 to -11.2

Table 4: Range of rainfall change (%) by 2060-2079[10]

	Annual	Summer	Autumn	Winter	Spring
Rainfall	-27 to +9	-13 to +27	-29 to +26	-38 to +4	-48 to +6

Table 5: 10th and 90th percentile range of rainfall change by 2080-2099[11]

The ratio of precipitation falling as snow or rain will change in a warming climate with less precipitation falling as snow. With continued warming, there is very high

[9] Compared to the baseline period (1990–2009).
[10] In the individual 12 NARCliM climate models across NSW and two regional clusters.
[11] In CSIRO/BoM climate projections for the Murray Basin.

confidence that snowfall, snow depth and the snow covered area will further decrease, particularly evident at low elevation areas.

NARCliM climate projections for snow in the Australian Alps are not yet available (research currently ongoing as at FID). In CSIRO and Bureau of Meteorology climate modelling,[12] years without snowfall (100% decline) at elevations similar to Cabramurra (1,419 m) start to be observed by 2030 in some climate models. At higher elevations (1,923 m), the reduction of snowfall is about 50 - 80% by 2090 (depending on greenhouse gas emission scenarios).

5.4 Inflow

There is reasonable consensus for a reduction in average runoff in southeast Australia due to reduced precipitation, increased evapotranspiration and decreased soil moisture in a warmer climate.[13] Most of the rainfall and runoff in the southern half of the southeast Australia region (including the Snowy Mountains) occurs in the cool-season, and almost all climate models indicate less winter-spring rainfall in the future.

Research by the South Eastern Australian Climate Initiative (***SEACI***)[14,15] used 15 global climate models to simulate future rainfall and runoff for catchments in the Murray-Darling Basin region. Table 6 below shows the projected changes in rainfall and runoff specifically for the Snowy Mountains Scheme under 1˚C (~2030) and 2˚C (~2060) of global warming. Overall, an increase in extremes is shown with significantly drier dry periods (5-10th percentile), slightly wetter wet periods (90 - 95th percentile) with an overall drying on average (median).

5.5 Fire regime

The Forest Fire Danger Index (***FFDI***) can be used to quantify fire weather. The FFDI combines observations of temperature, humidity and wind speed with an estimate of the fuel state. Severe fire weather occurs when the FFDI exceeds 50. South-east Australia has observed a statistically significant increase in FFDI since the 1970s with extension of the fire season further into spring and autumn. This trend is expected to continue in the future with a projected increase in average fire weather as well as severe fire weather days in summer and spring across south-east Australia. NARCliM modelling suggests that the Snowy Mountains region could expect 0-1 additional severe fire weather days per year (i.e. FFDI > 50) by 2060-2079.

5.6 Climate variability

Southeast Australia, including the Snowy Mountains, experiences significant seasonal and annual climate variability which is expected to continue in a

[12] (CSIRO and Bureau of Meteorology 2015).
[13] ibid.
[14] The South Eastern Australian Climate Initiative http://www.seaci.org/.
[15] (Chiew et al. 2011).

changing climate. Various competing and interacting drivers influence climate in the Snowy Mountains.

The most dominant and well-known of these drivers is the El Niño Southern Oscillation (***ENSO***), a tropical Pacific Ocean mode which strongly modulates south-eastern Australian rainfall on interannual time scales. The Indian Ocean Dipole (***IOD***) is a related mode which also strongly controls rainfall amounts in the region, and tends to act in consonance with ENSO. Both ENSO and the IOD are linked to periods of drought and flood in the Snowy Mountains. Recent research suggests that El Niño and positive IOD (dry) events are likely to increase in intensity and frequency, and may become more frequent, with little change to the frequency of extreme La Nina (wet) events.[16]

The Southern Annular Mode (***SAM***) is another mode which influences weather in south-eastern Australia. This mode is linked to the strength of the subtropical ridge and modulates the latitude of the 'storm track,' and thereby the frequency with which rainfall bearing weather systems arrive. Over the last 50 years a positive trend in the SAM, (i.e. a southward retreat of the storm track) has resulted in reduced winter rainfall. Climate models suggest that both the positive trend in SAM and a reduction in cool-season precipitation are expected to continue in the future.[17]

6 Definitions and abbreviations

ENSO	El Niño Southern Oscillation
FFDI	Forest Fire Danger Index
IOD	Indian Ocean Dipole
KNP	Kosciuszko National Park
MJA	Marsden Jacob Associates
NEM	National Energy Market
RES	Ratings Evaluation Service
SAM	Southern Annular Mode
SEACI	South Eastern Australian Climate Initiative

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