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Artist's Impression

Environmental Impact Statement – Chapter 14: Climate change risk

Warragamba Dam Raising

Reference No. 30012078
Prepared for WaterNSW
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Contents

List of Tables

List of Figures

14 Climate change risk

This chapter provides an assessment of climate change risk during construction and operation of the Warragamba Dam Raising. The relevant Secretary's Environmental Assessment Requirements (SEARs) are shown in Table 14-1.

Table 14-1. Secretary's Environmental Assessment Requirements: Climate change risk

Desired performance outcomes	Secretary's Environmental Assessment Requirements[1]	Where addressed
7. Climate Change Risk Desired performance outcome: The Project is designed, constructed and operated to be resilient to the future impacts of climate change.	1. The Proponent must assess the risk and vulnerability of the Project to climate change in accordance with the current guidelines.	Section 14.4 Section 14.5
	2. The Proponent must quantify specific climate change risks with reference to the NSW Government's climate projections at 10 km resolution (or lesser resolution if 10 km projections are not available) and incorporate specific adaptation actions in the design.	Section 14.2 Section 14.4 Section 14.5 Section 14.6 Section 14.7

1 Note: this chapter specifically addresses SEAR 7 in addition to those general requirements of the SEARs applicable to all chapters and as identified as such in Chapter 1 (Section 1.5, Table 1-1).

The assessment is supported by detailed investigations, which have been documented in Appendix G (Climate change assessment report). This assessment also references various EIS chapters, including Chapter 3 (Strategic justification and Project need) and Chapter 15 (Flooding and hydrology).

The proposed management and mitigation measures in this Chapter are collated in Chapter 29 (Environmental impact statement synthesis, Project justification and conclusion).

14.1 Assessment methodology

Climate change risk relevant to the Project was assessed in accordance with applicable standards and guidelines, including:

- *Climate Change Impacts & Risk Management: A Guide for Business and Government* (Department of the Environment and Heritage (DoEH) 2006)
- *Australian Standard/New Zealand Standard 3100:2009 Risk Management – Principles and Guidelines*
- *Australian Standard AS 5334:2013 Climate change adaptation for settlements and infrastructure – A Risk-based Approach.*

The climate change assessment methodology is detailed in Appendix G (Climate change assessment report, Section 4). The overall approach comprised the following steps:

1. establishing the context (scope)
2. identifying relevant risks (risk screening)
3. analysing the risks (risk assessment)
4. evaluating relevant risks (risk assessment)
5. treating risks (adaptation).

Climate risks were screened for relevance to the Project and risk scenarios were developed for each of the relationships identified between project activities and climate risks. Each of the risk scenarios were then evaluated through a risk workshop involving WaterNSW, Infrastructure NSW, and other key stakeholders. During the workshop, each risk scenario was evaluated as to the likelihood of the risk occurring, the consequence should it happen, and assigned respective likelihood and consequence ratings. Likelihood criteria were adopted from AS/NZS 5334:2013, and consequence criteria from the risk management framework. The overall risk rating was then assigned using the matrix provided in AS/NZS 5334:2013.

In accordance with AS/NZS 5334: 2013 existing controls already, or expected to be, applied through design and construction were also considered. Risks evaluated as extreme or high were, where practicable, applied treatment. Risks evaluated as medium were considered for treatment on an individual basis. Risks evaluated as negligible or low did not require further consideration. Where practicable, risk treatments were identified to reduce the initial unmitigated risk rating.

14.2 Scope of the assessment

This assessment has considered the impact of relevant climate projections on the Project, rather than the impact of the Project on or mitigating the impacts of future climate change. The relevance of climate variables that potentially pose a risk to the Project were determined through an initial risk screening, as per the Australian Government's report *Climate Change Impacts & Risk Management – A Guide for Business and Government* (DoEH 2006). Project screening is presented in Appendix G (Climate change assessment report, Section 5.1), which identified the following climate variables:

- extreme heat – hot days, heatwaves
- flood producing rains – for example, east coast lows (ECLs)
- extended wet periods
- severe storms
- fire weather.

In relation to flooding, the assessment considered only flood risk to the construction and operation of the dam. The assessment of climate change impacts on the flood risk of the Hawkesbury-Nepean catchment for the current and proposed raised Warragamba Dam was not the purpose of this assessment. Flood risk in the Hawkesbury-Nepean Valley was assessed by WMAwater (2018), and is discussed in Chapter 3 (Strategic justification and project need) and Chapter 4 (Project development and alternatives).

The Project timeframes assessed were:

- construction: 2021-2025
- operation (design-life): 2025-2125.

In relation to the climate projections referenced in this document, this corresponds to:

- construction: NSW and ACT regional climate modelling (NARCliM) near-future projections, which represent 2020 to 2039, and are referred to in this assessment as '2030 projections'
- operation (design-life): NARCliM far-future projections, 2060 to 2079, and are referred to in this assessment as '2070 projections'.

The basis for selecting these timeframes, as well as discussion on the selected projections are provided in Appendix G (Climate change assessment report, Section 3).

The risk assessment only considered activities or outcomes where the proponent had ownership, direct control, or influence. Impacts of climate change to activities or outcomes out of the Project's influence were not assessed. These include climate change impacts to biodiversity, land-use and property, water (hydrology and water quality), and socio-economic values. These impacts were considered likely to happen regardless of the Project. However, impacts to these aspects from the construction and operation of the Project are considered in Chapters 8 to 12 (Biodiversity), Chapter 11 (Aquatic ecology), Chapter 15 (Flooding and hydrology), Chapter 21 (Socio-economic, land use and property), and Chapter 27 (Water quality).

The area(s) considered for the assessment were decided in the context of both the stage of the works (construction and operation) and geographic extent of possible effects and impacts. The study area included the areas upstream and downstream of the dam that could be affected by the future operation of the dam with a raised dam wall, as well as the construction footprint. Figure 14-1 shows the study area, which includes:

- construction area: In and around the existing dam, including the wall, a central drum gate and spillway, four radial gates and auxiliary spillway, as well as auxiliary access roads and dam site buildings. The township of Warragamba and areas immediately upstream and downstream of the dam as well as the immediate road network are included in the construction study area because they are likely to be impacted during construction
- upstream study area: comprising five rivers, the Coxs, Kowmung, Wollondilly, Nattai and Kedumba Rivers (and their tributaries), as well as the Greater Blue Mountains World Heritage Area, several national parks (Blue Mountains, Kanangra-Boyd, Nattai), and state conservation areas (Yerranderie, Nattai, Burragorang)
- downstream study area: comprising five rivers and four major creeks: the Hawkesbury, Nepean, Grose, Colo, and Macdonald Rivers, and the Erskine, Webbs, South, and Cattai Creeks.

14.3 Existing environment

The objective of the Project is to reduce flood risk to life, property and social amenity from regional floods in the Hawkesbury-Nepean Valley now and in the future, which is likely to become increasingly important due to climate change. Rainfall and flood modelling studies undertaken to inform the detailed design were critical in informing the level to which the Dam would need to be raised (WMAwater 2018). Rainfall and flood modelling, and the impacts this may have on the flood risk of the Hawkesbury-Nepean Valley is discussed in Chapter 15 (Flooding and hydrology).

14.3.1 Historical temperature and rainfall

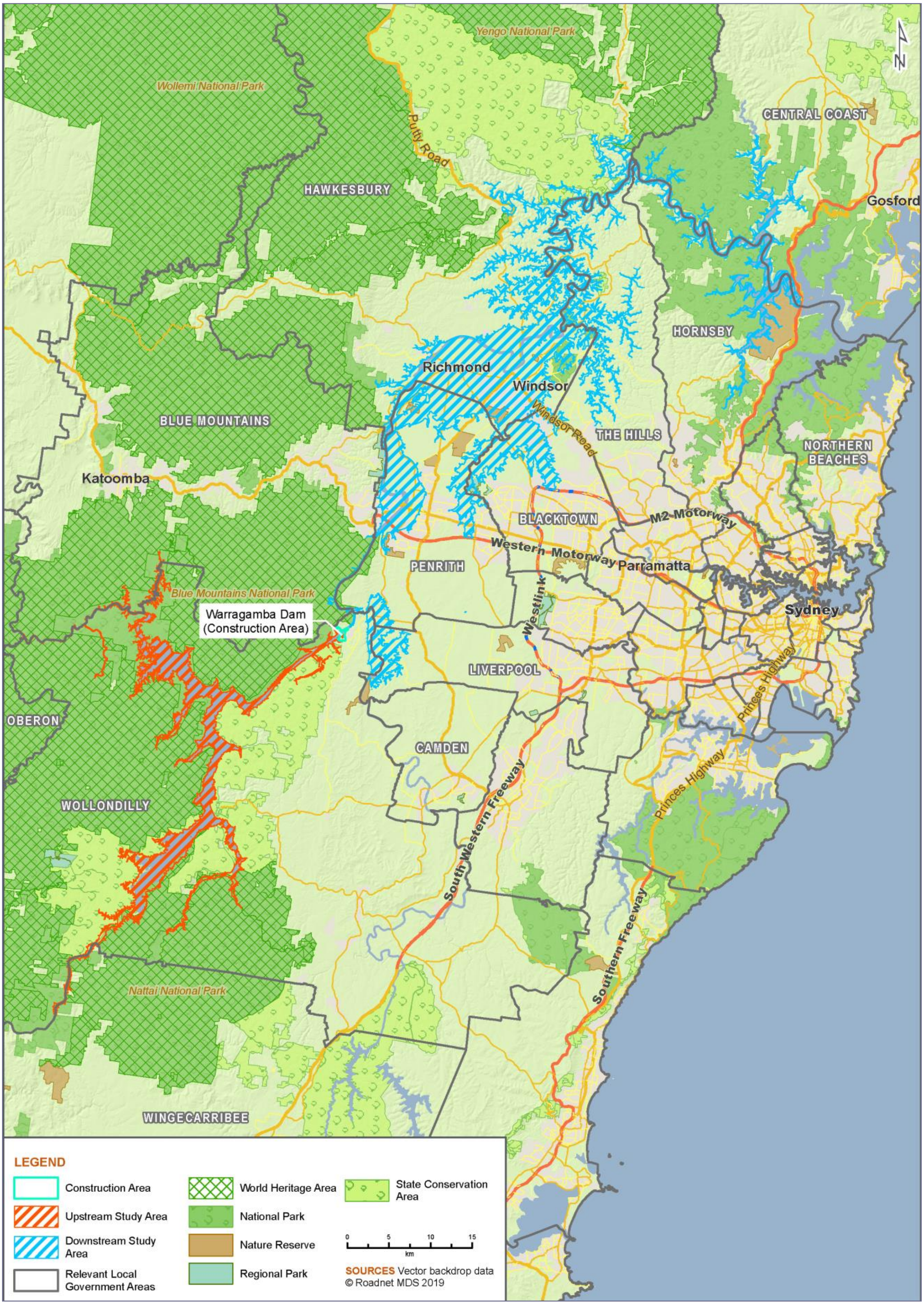
The Hawkesbury-Nepean catchment covers 21,400 square kilometres and extends from Barrenjoey in the east, north to Putty and the Wollemi National Park, south past Goulburn, and west to the limits of the Blue Mountains. From the headwaters to the river mouth, the elevation changes by about 1,290 metres. This contrasting elevation and landscape present significant variations in climate and weather conditions across the catchment. As such, historical and existing climate and weather were summarised from a series of weather stations across the catchment.

Temperature and rainfall averages for the catchment are summarised as follows:

- January is usually the hottest month, with the mean maximum temperature ranging from 23.4 °C in the upper catchment (at Katoomba) to 31.0 °C in the lower catchment (at Penrith Lakes)
- July is usually the coldest month with the mean maximum temperature ranging from 8.7 °C in the upper catchment (at Oberon) to 17.8 °C in the lower catchment (at Penrith Lakes)
- average annual rainfall ranges from 1,401.9 millimetres in the upper catchment (at Katoomba) to 624.6 millimetres in the southern catchment (at Goulburn)
- January to March are usually the wettest months, while July to September are usually the driest months
- extreme hot days (>35 °C) in the downstream study area, east of Penrith, average fewer than ten per year, which is largely due to proximity to the coast
- extreme hot days (>35 °C) west of Penrith (which includes the Project construction area) average 10 to 20 per year (Office of Environment and Heritage (OEH) 2014b).

A more detailed assessment of historical and existing weather and climate is presented in Appendix G (Climate change assessment report, Section 2).

Figure 14-1. Warragamba Dam Project study area



14.3.2 Changing weather and climate

Globally, weather and climate are changing in response to a warming climate system. The fifth (and latest at the time of this assessment) Intergovernmental Panel on Climate Change (IPCC) assessment report (AR) states that globally averaged combined land and ocean surface temperatures warmed by 0.85°C between 1880 and 2012, much of this occurring in the latter decades of the 20th century and in the early 21st century. This warming pattern was near universal across the globe (IPCC 2013). Globally averaged air temperatures have warmed by 1°C since records began in 1850, and each of the last four decades has been warmer than the previous (Bureau of Meteorology (BoM) & Commonwealth Scientific and Industrial Research Organisation (CSIRO) 2018). Global average sea-level rise between 1971 and 2010 occurred at a rate of 1.7 millimetres per year, accelerating to 3.2 millimetres per year between 1993 and 2010 (IPCC 2013, BoM 2018).

Atmospheric concentrations of all the major long-lived greenhouse gases (carbon dioxide, methane, nitrous oxide, fluorinated gases) continue to increase. Globally averaged carbon dioxide (CO_2) concentrations have been consistently above 400 parts per million since 2016, and CO_2-equivalent concentrations consistently above 500 parts per million, for the first time in 800,000 years (BoM & CSIRO 2018). The main contributor to the steady growth of atmospheric CO_2 concentrations remains emissions from the combustion of fossil fuels.

In Australia, long-term climate observations (that is, 1910-2013 for the Sydney region) demonstrate that temperatures have been increasing since about 1960, with significantly higher temperatures experienced since 1980 (OEH 2014b). Seven of the hottest years on record have occurred since 2005: 2005 (3rd), 2013 (2nd), 2014 (6th), 2016 (7th), 2017 (5th), 2018 (4th), 2019 (1st) (BoM & CSIRO 2020). This warming trend occurred against a background of year-to-year climate variability, largely associated with El Niño and La Niña in the tropical Pacific Ocean (BoM 2018). Sea surface temperatures have warmed by nearly 1°C since 1910, with the past seven years in the top ten warmest on record (BoM 2018). Regionally averaged air temperatures have warmed by 1°C since 1910, contributing to an increase in the frequency of extreme heat events (BoM & CSIRO 2018). The number of extreme temperature events (that is, days above 35°C and or heatwave events) occurring each year has also increased since the 1980s (BoM & CSIRO 2016).

Rainfall patterns across Australia vary greatly over both short (that is, years) and long (that is, decades) timeframes, influenced by El Niño and La Niña. Despite these natural variations, long-term trends are evident. In south-east Australia, rainfall for the period 1996 to 2014 decreased by about 11 percent of the long-term average based on data recorded since 1900 (BoM & CSIRO 2016). This drying trend was particularly strong in late-autumn and winter. Changes to rainfall intensity however, are more difficult to ascertain. Some studies show no trend, while others show a small but increasing trend of increased heavy rain events across Australia in the past five decades (BoM & CSIRO 2016).

Changing trends in destructive storms and dangerous fire weather have also been observed, with both becoming more common in recent decades (BoM & CSIRO 2016). In NSW, extreme weather and climate events, across all categories including extreme heat, bushfires, drought, extreme rainfall and storms are becoming increasingly common. The greater Sydney region (which includes the Project catchment area) is regularly subject to extreme weather and climate events, particularly extreme rainfall, storms and bushfires (Climate Council 2017).

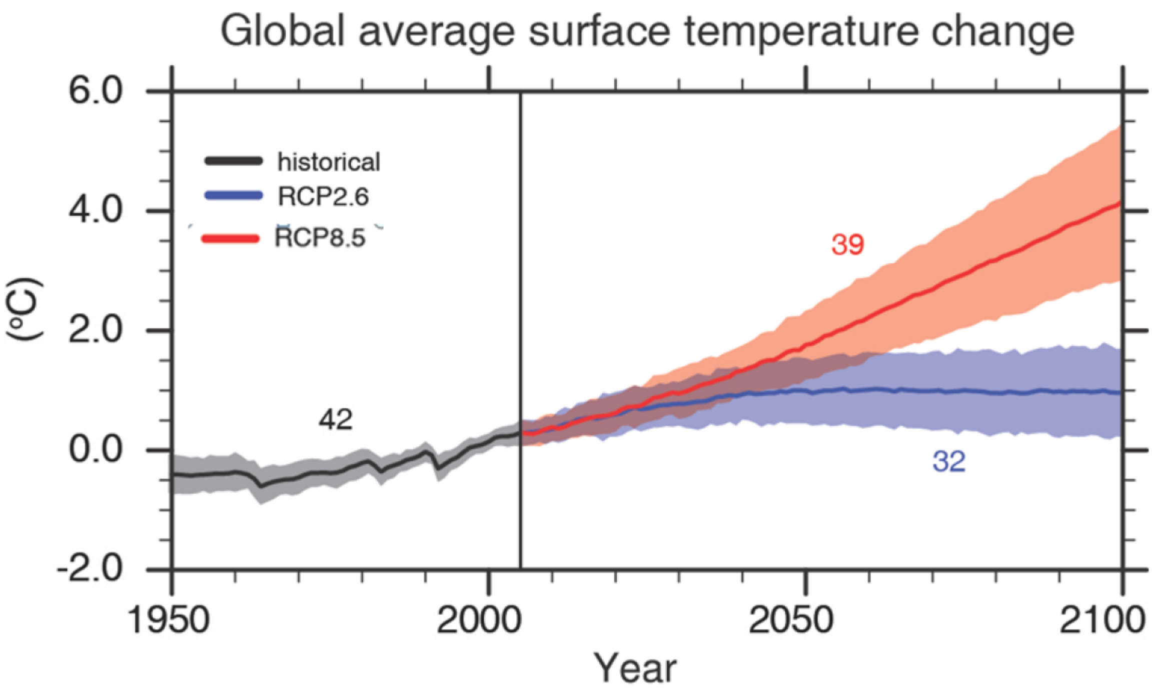
14.3.3 Climate change projections for the study area

The climate system and projected climatic changes have been modelled using various future greenhouse gas emissions scenarios, which themselves represent modelled estimates of future atmospheric concentrations of greenhouse gases. These emissions scenarios are based on assumptions regarding future demographics and implementation of greenhouse gas reduction protocols.

The IPCC produces assessment reports (AR), which review and synthesise the current scientific knowledge on climate change, and present global and regional climate patterns and projections. The fifth assessment report (AR5) was published in 2013 and used different representative concentration pathways (RCPs) to define climate projections for four future emissions scenarios (IPCC 2013). RCPs were developed to represent possible future emissions and concentration scenarios based on current knowledge. The RCPs focus on the concentrations of greenhouse gases that lead directly to a changed climate and include a 'pathway' – 'the trajectory of greenhouse gas concentrations over time to reach a particular radiative forcing at 2100' (Department of the Environment (DoE) n.d).

The datasets associated with each RCP are based on historic information and a set of plausible assumptions on future energy sources, population growth, economic activity, and other socio-economic factors, with and without climate mitigation policies (for example, RCP8.5 = minimal effort to curb emissions; RCP2.6 = strong mitigation efforts). Temperature change associated with the two extremes of the RCPs – RCP2.6 and RCP8.5 are shown in Figure 14-2.

Figure 14-2. IPCC Assessment Report 5 global average surface temperature change (IPCC 2013)



Solid lines = averages; shading = range of outcomes; numbers = number of model runs used to generate results. Temperature baseline (0.0 °C) was set to the average from 1986-2005. RCP = representative concentration pathway.

This assessment considered projections derived from several sources, which represent both the worst case and the current trajectory for emissions and warming scenarios as follows:

- NARCliM – which uses a single RCP8.5, high emissions scenario and applies it to the weather research and forecasting (WRF) model to develop high-resolution models for meteorological variables. NARCliM provides dynamically downscaled climate projections for south-east Australia at a 10 kilometre resolution, in line with the CORDEX (Coordinated Regional Climate Downscaling Experiment) framework.
- Centre for Australian Weather and Climate Research Projections - a collaboration between CSIRO and the Bureau of Meteorology, which developed the Australian Community Climate and Earth-System Simulator, available through *Climate Change in Australia* (CSIRO & BoM n.d). Climate projections are provided for all of the AR5 RCPs, for eight 'clusters' in Australia, which are further divided into smaller regions or 'sub-clusters' to provide finer-scale spatial resolution. The proposal site is within the east coast south sub-cluster.
- *NSW Climate Impact Profile – The Impacts of Climate Change on the Biophysical Environment of New South Wales* (Department of Environment, Climate Change and Water (DECCW) 2010e) provides climate projections for a single, high-emissions scenario.

The NARCliM projections complement those provided through *Climate Change in Australia*. Both use large-scale data from multiple global climate models (GCMs). However, the national projections from *Climate Change in Australia* use GCMs from the World Climate Research Programme's Coupled Model Inter-comparison Project phase 5 (CMIP5), while NARCLiM uses data from the earlier CMIP3 project. The NARCLiM modelling dynamically downscales GCM outputs to provide finer, high-resolution regional climate projections. Climate projections from both NARCliM and *Climate Change in Australia* have been referenced for this assessment.

The SEARs state that the proponent must adopt the NSW Government climate model outputs (that is, NARCliM) to assess risks to the Project. The NARCliM model outputs only provide for near (2020-2039) and far future (2060-2079) scenarios. These are referenced as projections for 2030 and 2070 respectively.

The climatic variables identified as potentially generating risk to the Project include extreme heat (for example, hot days and heatwaves), flood producing rains (for example ECLs), extended wet periods, severe storms (for example, wind, hail, lightening), and extreme fire weather. Table 14-2 provides a summary of projections for these climatic variables relevant to the study area.

A more detailed description of each of the climate model projection datasets is provided in Appendix G (Climate change assessment report, Section 3).

Table 14-2. Climate change projections relevant to the study area (OEH 2014b)

Climate variable	Climate projections for 2030[1]	Climate projections for 2070[1]
Mean maximum temperature	+0.7°C (range +0.3°C to +1.0°C)	+1.9°C (range +1.6°C to +2.5°C)
Hot days (>35°C) – eastern Sydney	+0 to 5 days per year	+5 to 15 days per year
Hot days (>35°C) – western Sydney	+5 to 10 days per year	+10 to 20 days per year
Heatwave events[2]	+0.4 events per year (range +0.1 to +0.8)	+3.5 events per year (range +0.4 to +7.0)
Average annual summer rainfall	0 to +5 percent change	+10 to 20 percent change
Average annual autumn rainfall	+5 to 10 percent change	+10 to 20 percent change
Average annual winter rainfall	-5 to + 5 percent change	0 to 10 percent change
Average annual spring rainfall	-5 to 0 percent change	0 to 10 percent change
Extreme rainfall[3]	+ 5 percent (range -3 to +12)	+2 percent (range -7 to +10)
Rainfall frequency	Variable	Variable
ECL frequency	Neutral	Neutral
ECL Intensity	Increase	Increase
Extreme fire weather days	0 to +2 days per year	+1 to +6 days per year
Atmospheric CO_2	Increase	Increase

1 Compared to current baseline
2 Heatwaves are defined as more than 3 consecutive hot days compared to 'normal' seasonal averages
3 Percent change 40-year, 1-day rainfall totals.'

14.4 Climate change risk assessment criteria

An initial risk screening was undertaken to consider the impact that all climate variables might have on key Project components. This process was intended to screen out minor risks, so that the risk assessment could focus on the risks that pose a medium or greater risk to the Project. The elements of the Project for which these climate-related impacts were considered against were determined based on a review of the Project description, consultation with WaterNSW, and refined during the risk assessment workshop, and comprised:

- upstream catchment (Figure 14-1)
- downstream catchment (Figure 14-1)
- existing dam infrastructure (upstream and downstream)
- construction elements/activities:
  - concrete pouring
  - temporary diversion(s)
  - embankments and groundworks
  - staging / timing
  - workforce
  - stakeholders – for example, Sydney Water
- operation elements/activities:
  - future dam infrastructure
  - downstream infrastructure
  - stakeholders – for example, Sydney Water.

Table 14-3 provides a summary of the identified relationships (those marked with a '✓'), which formed the basis of the development of risk scenarios in subsequent sections, noting that one relationship might result in multiple risks and multiple relationships may combine to create a single risk.

Table 14-3. Project risk screening

Climate variable	Project component/consideration											
	Upstream catchment	Downstream catchment	Existing dam infrastructure	Concrete pouring	Temporary diversions	Embankments & groundworks	Construction staging/timing	Future dam infrastructure	Downstream infrastructure	Construction workforce	Stakeholders	Operations
Mean maximum temperature	-	-	-	-	-	-	-	-	-	-	-	-
Mean minimum temperature	-	-	-	-	-	-	-	-	-	-	-	-
Extreme heat - hot days	-	-	-	✓	-	-	✓	-	-	✓	-	-
Extreme heat - heatwaves	-	-	-	✓	-	-	✓	-	-	✓	-	-
Annual average rainfall	-	-	-	-	-	-	-	-	-	-	-	-
Extreme rainfall (intensity)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Extended rainfall (frequency)	-	-	-	✓	✓	✓	✓	-	-	-	✓	-
Extreme weather - ECLs	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Extreme weather - storms	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Extreme weather - fire weather	✓	✓	✓	✓	-	-	✓	✓	✓	-	-	✓
Sea level rise	-	-	-	-	-	-	-	-	-	-	-	-
Mean wind speed	-	-	-	-	-	-	-	-	-	-	-	-
Evaporation	-	-	-	-	-	-	-	-	-	-	-	-
Atmospheric CO_2	-	-	✓	✓	✓	-	-	-	✓	-	-	✓

Based on the initial risk screening, climate variables excluded from the risk assessment were:

- mean maximum temperature
- mean minimum temperature
- annual average rainfall
- sea level rise
- mean wind speed
- evaporation.

Justification for why these climate variables were excluded is provided in Appendix G (Climate change assessment report, Section 5).

The initial risk screening determined that extreme heat, which includes hot days and heatwaves, could impact upon:

- concrete pouring: concrete pouring and setting has an optimal temperatures range, and as such an increase in hot days and heatwaves associated with climate change may impact concrete pouring activities for the Project
- construction staging/timing: an increase in hot days and heatwaves associated with climate change may impact construction staging due to delays in concrete pouring (as discussed above) and reduced workforce capacity (as discussed below)
- construction workforce: the construction workforce could be impacted by an increase in extreme heat through increased occurrence of heat stress and dehydration, leading to more lost time days.

The initial risk screening determined that extreme rainfall, which includes extended wet periods and extreme rainfall events (such as flood producing rains) could impact upon:

- Project construction:
  - extended wet periods may impact upon the staging / timing of the Project.

- Project operation:
  - an increase in flood producing rains may reduce the benefit of the flood mitigation zone (FMZ)
  - an increase in flood producing rains may increase the frequency of inundation of the FMZ, leading to increased environmental impacts.

The initial risk screening identified that extreme weather events, which includes ECLs, storms and fire weather, could present a high risk to the construction and operation of the Project. As discussed, flood producing rains in the study area are often associated with ECLs. Initial risk considerations relating to rainfall are discussed in Chapter 15 (Flooding and hydrology). Extreme weather is also associated with high winds, flying debris and lightning, all of which may present risk to Project infrastructure and the construction workforce. An increase in fire weather also presents a risk to Project infrastructure and the construction workforce.

An increase in atmospheric CO_2 may lead to an increase in rainfall acidity, which also poses a risk to Project infrastructure.

These are initial risks identified during the screening process. Additional risks may be identified through the detailed risk assessment, which should be undertaken prior to the design being finalised.

14.5 Assessment of potential construction impacts

Assessment of construction risk scenarios is presented in Table 14-4. These were assigned a likelihood and consequence, and subsequent risk rating during the risk assessment workshop. Note that this table only shows unmitigated risks rated 'high' or above. The complete set of risks, details on the likelihood and consequence criteria, and workshop attendees are provided in Appendix G (Climate change assessment report, Section 5).

Table 14-4. Construction risk assessment - unmitigated

Construction risk scenario/impact	Likelihood	Consequence	Risk rating
Increase in consecutive extended wet periods – flooding impact on works, timing, and construction staging	Likely	Moderate. Impacts relating to: ▪ capability and service delivery ▪ compliance and legal ▪ financial ▪ reputation	High
Increase in consecutive extended wet periods – flooding or saturation of embankments and ground conditions	Likely	Moderate. Impacts relating to: ▪ capability and service delivery ▪ environment and heritage ▪ financial.	High
Increased number of hot days/heatwaves – impact to construction staging/timing	Almost certain	Moderate. Impacts relating to: ▪ financial ▪ compliance and legal ▪ reputation.	High
Increased number of hot days/heatwaves – impact on times of day that concrete could be poured	Almost certain	Moderate. Impacts relating to: ▪ financial ▪ compliance and legal ▪ reputation.	High

Where possible, appropriate adaptation or mitigation measures were proposed for each risk scenario rated high or above. These include adaptation measures that have or will be included in the design development, construction, and operation of the Project.

The accepted level of risk for each risk scenario will vary depending on the nature of the risk and impact, and whether there are any feasible options to reduce predicted impacts. Existing controls and proposed adaptation measures were determined during the risk assessment workshop. These are summarised in Table 14-5.

Table 14-5. Residual construction risks following consideration of existing treatments or proposed treatments

Construction risk / impact	Risk rating	Existing controls	Proposed treatment	Residual risk
Increase in consecutive extended wet periods – flooding impact on works, timing, and construction staging	High	Program allowance for stoppages. Contractual inclusions around insurances.	Temporary mechanisms in place during construction to capture floods. Timing of major works outside of ECL sequencing/seasonality.	Medium
Increase in consecutive extended wet periods – flooding or saturation of embankments and ground conditions	High	Program allowance for stoppages. Contractual inclusions around insurances. Erosion and sediment control.	Temporary mechanisms in place during construction to capture floods. Timing of major works outside of ECL sequencing/seasonality.	Medium
Increased number of hot days/heatwaves – impact to construction staging/timing due to reduced workforce capacity	High	Program allowance for stoppages Contractual inclusions around insurances.	Allowances for work outside of standard hours in approvals and licenses.	Medium
Increased number of hot days/heatwaves – impact on times of day that concrete could be poured	High	Program allowance for stoppages. Contractual inclusions around insurances.	Allowances for work outside of standard hours in approvals and licenses. Cooling concrete aggregates and materials. Program concrete pours within constraints dictated by temperatures.	Medium

14.6 Assessment of potential operational impacts

Assessment of operational risk scenarios is presented in Table 14-6. These risks were assigned a likelihood and consequence, and subsequent risk rating during the risk assessment workshop. Note that this table only shows unmitigated risks rated high or above. The complete set of risks, details on the likelihood and consequence criteria, and workshop attendees are provided in Appendix G (Climate change assessment report, Section 5).

Table 14-6. Operational risk assessment – unmitigated

Operational risk	Likelihood	Consequence	Risk Rating
Increase in extreme flood producing rains – flood mitigation benefits of the FMZ are reduced	Almost certain	Major. Impacts relating to: ▪ health and safety ▪ capability and service delivery ▪ environment and heritage ▪ financial ▪ reputation.	Extreme

Operational risk	Likelihood	Consequence	Risk Rating
Increase in extreme flood producing rains – upstream increased inundation frequency in the zone immediately above the full supply level (FSL), contributing to potential environmental impacts.	Almost certain	Moderate. Impacts relating to: ▪ environment and heritage.	High

Where possible, appropriate adaptation or mitigation measures were proposed for each risk scenario rated high or above. These include adaptation measures that have, or will be, included in the design development, construction, and operation of the Project.

The accepted level of risk for each risk scenario will vary depending on the nature of the risk and its associated impact(s), and whether there are any feasible options to reduce predicted impacts. Existing controls and proposed adaptation measures were determined during the risk assessment workshop. These are summarised in Table 14-7.

Table 14-7. Residual operational risks following consideration of existing treatments or proposed treatments

Operational risks	Risk rating	Existing controls	Proposed treatment	Residual risk
Increase in extreme flood producing rains – flood mitigation benefits may be lowered (would depend on timing of rainfall event and whether FMZ was still being emptied)	Extreme	Warragamba Dam currently has no flood mitigation capacity (when at FSL), and the flood risk would increase with climate change. The Project would provide flood mitigation benefits compared to the current dam under all projected climate change scenarios	Raise the dam wall to provide an FMZ (the Project). Provide for future increase of the FMZ (subject to planning approval) if future climate scenarios require including an additional three metres in the abutment height. Other work-streams being implemented under the Hawkesbury-Nepean Flood Strategy.	High
Increase in extreme flood producing rains – upstream increased inundation frequency in the zone immediately above FSL, contributing to potential environmental impacts.	High	Warragamba Dam flood operating protocol	Emptying the FMZ as soon as possible (from a period of hours to around two weeks) after a flood event would maximise the flood mitigation availability and benefits of the FMZ. It would reduce the inundation time and impacts on upstream catchments.	Medium

14.7 Environmental management measures

Peer reviewed climate change research found that by 2090 it is likely an additional three metres of spillway height would be required to provide similar flood mitigation outcomes as the current flood mitigation proposal. Raising the dam side walls and roadway by an additional three metres may not be feasible in the future, both in terms of engineering constraints and cost. The current design includes raising the dam side walls and roadway by 17 metres now to enable adaptation to projected climate change. Any consideration of raising spillway heights is unlikely before the mid to late 21st century and would be subject to a separate planning approval process. The 17 metre raising height of the dam abutments (side walls) and roadway have been considered and accounted for in the EIS and design. The potential maximum height and duration of upstream inundation remains consistent with what was originally proposed in 2016.

The design development would also incorporate climate adaptation measures for all temporary and permanent infrastructure associated with the Project. This may include temporary roads, construction compounds, batching plants, environmental flows infrastructure, water transmission pipelines, and recreational facilities.

Other work-streams being or to be implemented under the Hawkesbury-Nepean Flood Risk Management Strategy would also provide climate adaptation.

Safeguards and management measures have been developed to avoid, minimise or manage potential risks identified in Chapter 15 (Flooding and hydrology). Relevant management and mitigation measures have been detailed below in Table 14-8. These mitigation and management measures have been incorporated in the environmental management measures in Chapter 29 (EIS synthesis, Project justification and conclusion).

Table 14-8. Management measures

Impact	ID	Environmental management measure	Timing	Responsibility
Climate Risk – general	CC1	Development of a Climate Risk Management Sub-Plan. The sub-plan would detail the safeguards and management measures required to be implemented during the construction of the Project. The plan should include monitoring to assess progress on major residual risks and serve as a continuous improvement mechanism to manage climate change risks as they become more robust into the future	Pre-construction	Construction contractor
Climate change – changes in extreme rainfall during construction	CC2	Design of temporary infrastructure, for example, coffer dams, diversions, to accommodate climate projections	Detailed design	Design lead
Climate change – changes in extreme rainfall during construction	CC3	Implement measures to protect the community from potential impacts associated with climate change during construction of the dam, which may include temporary flood barriers	Detailed design	Design lead
Climate change – changes in extreme rainfall during design life	CC4	Detailed design to consider inclusion of design / construction elements to allow the dam to be more readily upgraded in the future to allow for climate change scenarios.	Detailed design	Design lead
Climate change – more intense extreme weather events during construction	CC5	Construction sequencing for major works to consider peak ECL season.	Pre-construction	Construction contractor
Climate change – general	CC6	Climate change to be considered during health and safety management planning	Pre-construction	Construction contractor

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SMEC is recognised for providing technical excellence and consultancy expertise in urban, infrastructure and management advisory. From concept to completion, our core service offering covers the life-cycle of a project and maximises value to our clients and communities. We align global expertise with local knowledge and state-of-the-art processes and systems to deliver innovative solutions to a range of industry sectors.

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