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Environmental Impact Statement – Appendix G: Climate Change Risk

Warragamba Dam Raising

Reference No. 30012078
Prepared for WaterNSW
10 September 2021

SMEC INTERNAL REF. 30012078

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Executive Summary

This report provides an assessment of the vulnerability of the Warragamba Dam Raising project (the Project) to potential impacts from climate change. This assessment has considered the impact of *relevant* climate change projections on the Project, rather than the impact of the Project on future climate change. The report addresses the requirements of the Secretary's Environmental Assessment Requirements (SEARs) and informed the environmental impact statement (EIS) for the Project.

Project background

The proposed flood mitigation works at Warragamba Dam involve raising the dam to provide capacity to facilitate flood mitigation. Raising the spillway crest height to create a flood mitigation zone (FMZ) would provide capacity to temporarily hold back around 1,000 gigalitres of inflows during flood events. The Project would also include the development and implementation of operation protocols for flood mitigation during a flood event.

In 2011 and 2012, significant floods in south-east Queensland and Victoria raised awareness across Australia about the impact of floods and the potential role dams play in mitigating the effects of floods. At the time, the NSW Government was drafting the State Infrastructure Strategy 2012-2032.

Among other infrastructure investments and reforms, the strategy recommended the review of major flood mitigation options available for the Hawkesbury-Nepean Valley, including options for raising Warragamba Dam. The review was commenced in 2013, with the Stage One review report released in 2014 (Department of Primary Industries 2014). The key outcomes from the review were as follows:

- current flood management and planning arrangements were insufficient in mitigating the risk
- no single mitigation option would address all the flood risk present in the Hawkesbury-Nepean Valley
- the raising of Warragamba Dam to capture flood inflows was the most effective single infrastructure measure that could have a major influence on mitigating flood levels during major flood events.

In 2016, the NSW Government committed to implement Phase One of the Hawkesbury-Nepean Flood Risk Management Strategy. Phase One focused on planning for the Project to raise Warragamba Dam for flood mitigation, as well as activities to reduce flood risk in the short-term, where possible. Funding has been allocated to undertake the detailed planning, concept design, environmental assessments, and community consultation for raising Warragamba Dam to create a flood mitigation zone. If approved, under relevant environmental planning legislation, phase one would culminate in a Final Business Case for Government consideration whether to progress with Phase Two – implementing the raising of Warragamba Dam – subject to environmental and planning approvals.

Existing environment

Warragamba Dam is in a narrow gorge on the Warragamba River, at the foot of the Blue Mountains National Park, about 65 kilometres west of Sydney. The damming of Warragamba River, completed in 1960, flooded the Burragorang Valley, creating Lake Burragorang. The lake's capacity is four times that of Sydney Harbour and provides about 80 percent of Sydney's water supply (WaterNSW 2018a). At present the dam is 142 metres high and 351 metres long, which makes it one of the largest domestic water supply dams in the world (WaterNSW 2018a).

The Warragamba River is within the Hawkesbury-Nepean catchment, of which the Warragamba Dam sub-catchment represents 80 percent of the total Hawkesbury-Nepean catchment at Penrith and 70 percent of the total catchment at Windsor (Infrastructure NSW 2017). The Hawkesbury-Nepean catchment covers an area of about 21,400 square kilometres (Department of Environment, Climate Change and Water 2010b). For the purposes of this assessment the catchment was divided into two sub-catchments – upstream and downstream of Warragamba Dam – each of which comprise several smaller catchments.

The topography downstream from Warragamba Dam consists of floodplains, undulating valleys, narrow constrained gorges at confluences of major rivers, as well as along the Hawkesbury and Lower Hawkesbury Rivers downstream from Sackville. Land-use in the downstream catchment is dominated by urban development, commercial and manufacturing services, with protected areas in the far east of the catchment.

The unique topography and geomorphology of the catchment creates unique flood risks during periods of intense rain. During such climatic events, the large upstream catchment and major tributaries of the downstream catchment can contribute significant floodwater volumes to the Hawkesbury-Nepean Valley. However, the downstream movement of floodwaters is stalled by natural choke points resulting in the back-up of floodwaters, and rapidly rising floodwaters across the floodplains of Wallacia, Penrith, and Richmond-Windsor.

The largest flood on record for the Hawkesbury-Nepean Valley occurred in 1867, when floodwaters reached an estimated 26.9 metres Australian Height Datum (mAHD) at Penrith and 19.3 mAHD at Windsor (close to 0.2 percent chance per year or a 1 in 500 chance in a year flood). Geological evidence from prior to European settlement, but under current climatic conditions, suggests that a 1 in 1000 chance in a year flood event has occurred in the valley (Infrastructure NSW 2017).

Climate change may further exacerbate flood risk and exposure due to the predicted increase in intensity, and distribution of rainfall across the catchment.

Historical and existing weather and climate

The Hawkesbury-Nepean catchment covers 21,400 square kilometres presenting 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.

Summary of current weather and climate for the Project area

Upper catchment	Lower Catchment
January is the hottest month with mean maximum temp. 23.4 °C	**January is the hottest month with mean maximum temp. 31.0 °C**
July is the coldest month with mean maximum temp. 8.7 °C	**July is the coldest month with mean maximum temp. 17.8 °C**
February records the warmest minimum (overnight) temp. 11.2 °C	**January records the warmest minimum (overnight) temp. 18.6 °C**
July records the coolest minimum (overnight) temp. -0.3 °C	**July records the coolest minimum (overnight) temp. 5.4 °C**
Annual rainfall averages 837-1,401 mm	**Annual rainfall averages 624-1,329 mm**
January to March are the wettest months	**January to March are the wettest months**
July to September are the driest months	**July to September are the driest months**

In coastal NSW, including the Hawkesbury-Nepean Valley, flash flooding and river flooding are often associated with east coast lows (ECLs), which occur on average ten times each year (Infrastructure NSW 2017). Extreme hot days (>35°C) in Sydney currently average fewer than ten per year, largely due to proximity to the coast. However, areas in western Sydney (including the study area) experience 10 to 20 hot days per year on average (Office of Environment and Heritage 2014).

Changing weather and climate

Globally, weather and climate are changing in response to a warming climate system, driven by increasing concentrations of greenhouse gases. In Australia, 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 2020). Concurrently, long-term climate observations (1910-2013) for the Sydney region demonstrate that temperatures have been increasing since about 1960, with significantly higher temperatures experienced since 1980.

In the southeast of the Australian continent, rainfall for the period 1996 to 2014 has decreased by about 11 percent of the long-term average based on data recorded since 1900 (BoM & CSIRO 2016). This drying trend is particularly strong in late-autumn and winter.

In NSW, extreme weather and climate events across all categories are becoming increasingly common. And 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 change projections

NSW and ACT regional climate modelling projections for the study area (OEH 2014) include:

- an increase in all temperature variables
- an increase in the number of hot days per year compared to the current average
- an increase in the intensity of heatwaves across NSW
- marginal increases in summer and autumn rainfall, but decreased winter and spring rainfall in the near-term (2030)
- increased rainfall across all seasons by up to 20 percent in the far-term (by 2070)
- an increase in rainfall extremes (intensity and duration)
- no change, or a small decline in the frequency of ECLs, but an increase in the number of intense ECLs
- an increase in dangerous fire weather.

Summary of climate change projections for the study area

Variable	Projections	
	2030	2070
Maximum temperature	+0.7 (0.3 to 1.0) °C	+ 1.9 (1.6 to 2.5) °C
Hot days – eastern Sydney	+5-15 days per year	+ 10-25 days per year
Hot days – western Sydney	+15-30 days per year	+ 20-40 days per year
Heatwaves	+ 1.6 (1.3 to 1.9) events per year	+ 4.7 (1.6 to 8.2) events per year
Summer rainfall	0 to +5 per cent	+10 to +20 per cent
Autumn rainfall	+5 to +10 per cent	+10 to +20 per cent
Winter rainfall	-5 to +5 per cent	0 to +10 per cent
Spring rainfall	-5 to 0 per cent	0 to +10 per cent
Extreme rainfall	+5 (-3 to +12) per cent	+2 (-7 to +10) per cent
ECL frequency	Neutral	Neutral
ECL intensity	Increase	Increase
Extreme fire days	Neutral-Increase, 9 to 11 days per year	Increase, 10 to 15 days per year

Climate change risk assessment

This climate change risk assessment was carried out in accordance with relevant standards and guidelines. The overall approach is focussed on risk management and includes five steps - establishing the context (scope), identifying risks (risk screening), analysing risks (risk assessment), evaluating risks (risk assessment), and treating risks (adaptation).

The scope of this assessment considered construction and operation of the Project. The assessment focussed on activities or outcomes over which the proponent has ownership, direct control or influence. 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 and the construction footprint.

Risk assessment outcome

The main impacts of climate change on the Project relate to projected changes in rainfall patterns. It is important to note that the key objective of the Project is to provide flood mitigation for downstream communities. The key proposal parameters (for example, raising the dam to create an FMZ) were considered through extensive modelling of rainfall and flooding (WMAwater 2019). (See Section 6, Table 6-1).

Summary of unmitigated high and extreme climate risks to the Project

Risk scenario	Unmitigated Risk level	Existing controls	Treatment/adaptation	Residual risk level
Increase in extreme flood producing rain: ▪ Operational - flood mitigation benefit of raising Warragamba Dam to create an FMZ is lowered.	Extreme	The current Warragamba Dam has no flood mitigation capacity, and the flood risk will increase with climate change. The Project will continue to have flood mitigation benefits compared to the current dam under all projected climate change scenarios	▪ Raising Warragamba Dam to create an FMZ ▪ Raising Warragamba Dam abutments by an additional three metres to be resilient to the future impacts of climate change and maintain the downstream benefits ▪ Other work-streams being implemented under the Hawkesbury-Nepean Flood Strategy.	High
Increase in extreme flood producing rain: ▪ Operational - upstream increased inundation frequency in the zone immediately above the full supply level, contributing to potential environmental impacts.	High	▪ Current H14 protocol for controlled discharge of water.	▪ Adaptive catchment management in partnership with relevant stakeholders. ▪ Flood drawdown framework prioritises emptying the FMZ to limit the inundation time/extent.	Medium
Increase in consecutive extended wet periods: ▪ Construction - flooding impact on works/ timing/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 east coast low (ECL) sequencing/ seasonality.	Medium
Increase in consecutive extended wet periods: ▪ Construction – 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
Increase in number of hot days/heatwaves: ▪ Construction - Construction timing/staging impacts.	High	▪ Program allowance for stoppages ▪ Contractual inclusions around insurances.	▪ Allowances for work outside of standard hours in approvals and licences. ▪ Program concrete pours within constraints dictated by temperatures ▪ Cooling concrete aggregates and materials.	Medium
Increase in number of hot days / heatwaves: ▪ Construction - Impacts on times of day during which concrete can be poured.	High	▪ Program allowance for stoppages ▪ Contractual inclusions around insurances	▪ Allowances for work outside of standard hours in approvals and licences.	Medium

Risk scenario	Unmitigated Risk level	Existing controls	Treatment/adaptation	Residual risk level
		▪ Program concrete pours within constraints dictated by temperatures ▪ Cooling concrete aggregates and materials.		

Risk treatment

For each of the identified potential impacts that climate change may have on the Project, appropriate adaptation measures have or will be proposed, wherever possible. These include adaptation measures that have or will be included in the design, construction, and operation of the Project.

Summary of recommended risk treatment

Climate variable	Existing/potential adaptation measures
Increase in extreme flood producing rainfall/increase in consecutive extended wet periods/increase in severe storm events, for example, ECLs.	▪ Flexibility in design by raising the abutments by an additional three metres to be resilient to the future impacts of climate change. ▪ Warragamba Dam Flood Operating Protocol prioritises emptying the flood mitigation zone to limit the inundation time/extent. ▪ Construction program allowance for stoppages. ▪ Construction contractual inclusions around insurances. ▪ Other work-streams being implemented under the Hawkesbury-Nepean Flood Strategy. ▪ Adaptive catchment management in partnership with National Parks and Wildlife (specific environmental management plan). ▪ Temporary mechanisms in place during construction to capture floods. ▪ Timing of major works outside of ECL sequencing/seasonality. ▪ Procedures for shutdown of critical infrastructure to minimise risk.
Increase in number of hot days/heatwaves.	▪ Construction program allowance for stoppages. ▪ Construction contractual inclusions around insurances. ▪ Program concrete pours within constraints dictated by temperatures. ▪ Cooling concrete aggregates and materials. ▪ Allowances for work outside of standard hours in approvals and licences.

This climate change risk assessment is intended to be an iterative process. At the time of preparation of this report, detailed design for the Project had not been completed. The detailed design would, as appropriate, incorporate design elements and construction methods or controls to minimise the relevant impacts associated with climate change. As such, this risk assessment should be revisited when the detailed design is complete; however, this is beyond the scope and timing of the EIS.

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1 Introduction

This report provides an assessment of the vulnerability of the Warragamba Dam Raising project to potential impacts from climate change. This assessment has considered the impact of relevant climate change projections on the Project, rather than the impact of the Project on future climate change. Impacts of the Project on climate change may relate to greenhouse gas emissions generated during construction and operation.

The report addresses the Secretary's Environmental Assessment Requirements (SEARs) and informs the environmental impact statement (EIS).

A preliminary environmental assessment report was provided to the Secretary of the then Department of Planning and Environment (DPE)[1], with the SEARs being issued on 30 June 2017. These were superseded by an updated version issued 13 March 2018.

SEAR 7 is directly relevant to the climate change risk assessment and this report and is provided in Table 1-1.

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

Desired performance outcome	Secretary's Environmental Assessment Requirements	Where addressed
7. Climate change risk 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. 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 3 Section 4 Section 5 Section 6

An assessment of the potential impacts of climate change on flooding and flood mitigation capability is required under SEAR 8. A separate specialist report has been prepared to address this SEAR and is summarised in Chapter 15 (Flooding and hydrology) of the EIS. Some of the outcomes and recommendations from the WMAwater (2018) assessment have been used in this report to develop climate change risk management actions.

1.1 Project background

The *State Infrastructure Strategy 2012-2032* recommended the review of major flood mitigation options available for the Hawkesbury-Nepean Valley, including options for raising Warragamba Dam. The review commenced in 2013 with the Stage 1 review report released in 2014 (DPI 2014). The key outcomes from the Stage 1 review are as follows:

- current flood management and planning arrangements were insufficient in mitigating the risk
- no single mitigation option would address all the flood risk present in the Hawkesbury-Nepean Valley
- the raising of Warragamba Dam to capture flood inflows was the most effective single infrastructure measure that could have a major influence on mitigating flood levels during major flood events.

The cost-benefit analysis included in the review, demonstrated that raising Warragamba Dam would provide, on average, a 75 percent reduction in flood damages, reducing the cost of repairs for urban flood damages by billions of dollars during large flood events.

[1] Now the Department of Planning, Industry and Environment (DPIE)

Although raising the dam was determined to significantly reduce the risk of a major flood, it would not eliminate it altogether, regardless of the height the dam was raised. Therefore, it was recommended that the raising of the dam be one of many risk mitigation approaches, including other non-infrastructure related strategies.

In 2017, Infrastructure NSW published *Resilient Valley, Resilient Communities: Hawkesbury-Nepean Valley Flood Risk Management Strategy* (Infrastructure NSW 2017). The objective of the strategy was to reduce risk to life, property and social amenity from floods in the Hawkesbury-Nepean Valley. The strategy included a range of targeted actions designed to deliver the following nine outcomes:

1. coordinated flood risk management across the valley
2. reduce flood risk by raising Warragamba dam wall
3. strategic and integrated land use and road planning
4. accessible contemporary flood risk information
5. an aware, prepared and responsive community
6. improved weather and flood predictions
7. best practice emergency response and recovery
8. adequate local roads for evacuation
9. ongoing monitoring, evaluation, reporting and improvement of the strategy.

The NSW Government has committed to implement Phase One of the Hawkesbury-Nepean Flood Risk Management Strategy. Phase one focused on planning for the Project to raise Warragamba Dam for flood mitigation, as well as activities to reduce flood risk in the short-term, where possible. Funding has been allocated to undertake the detailed planning, concept design, environmental assessments, and community consultation for the raising of Warragamba Dam by to create a flood mitigation zone (FMZ). If approved, Phase One would culminate in a Final Business Case for Government consideration whether to progress with phase two – implementing the raising of Warragamba Dam– subject to environmental and planning approvals.

To support phase one assessments, and in recognition of the potential impacts associated with climate change, the Hawkesbury-Nepean Valley Flood Risk Management Directorate commissioned climate and hydrological modelling to be undertaken. The modelling included an assessment of potential future flood impacts associated with a range of climate change projections for rainfall, including worst-case, and raising Warragamba Dam (WMAwater 2019). However, additional climate change and hydrological modelling indicates that by about 2090 the dam may need to be raised by an additional three metres to provide the same degree of flood mitigation.

1.2 The Project

Warragamba Dam Raising is a project to provide flood mitigation to reduce the significant existing risk to life and property in the Hawkesbury-Nepean Valley downstream of the dam. This would be achieved through raising the level of the central spillway crest by around 12 metres and the auxiliary spillway crest by around 14 metres above the existing full supply level (FSL) for temporary storage of inflows. The spillway crest levels and outlets control the extent and duration of the temporary upstream inundation. There would be no change to the existing maximum volume of water stored for water supply.

The NSW Government announcement in 2016 proposed that the dam wall be raised by 14 metres. Subsequently, the SEARs required the Project to be designed, constructed and operated to be resilient to the future impacts of climate change and incorporate specific adaptation actions in the design.

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 Project also includes providing infrastructure to facilitate variable environmental flows to be released from Warragamba Dam.

The Project would include the following main activities and elements:

- demolition or removal of parts of the existing Warragamba Dam, including the existing drum and radial gates
- thickening and raising of the dam abutments

- thickening and raising of the central spillway
- new gates or slots to control discharge of water from the FMZ
- modifications to the auxiliary spillway
- operation of the dam for flood mitigation
- environmental flow infrastructure.

The Project would take the opportunity, during the construction period for the dam raising, to install the physical infrastructure to allow for management of environmental flows as outlined in the NSW Government's *2017 Metropolitan Water Plan*. However, the actual environmental flow releases themselves do not form part of the Project and are subject to administration under the *Water Management Act 2000*.

1.2.1 Operation of the dam for flood mitigation

Operational objectives in order of priority are to:

- maintain the structural integrity of the dam
- minimise risk to life
- maintain Sydney's water supply
- minimise downstream impact of flooding to properties:
- minimise environmental impact
- minimise social impact.

There would be two different modes of operation for the Project: normal and flood operations. In both modes Warragamba Dam would continue to store and supply up to 80 percent of Sydney's drinking water. The storage capacity, which is the dam's FSL, would not change. The current and future operation of the dam is shown in Figure 1-1 and Figure 1-2 respectively.

1.2.1.1 Normal operation

Normal operation would occur when the dam storage level is at or lower than FSL.

Normal operation mode for the modified dam would be essentially the same as current operations, apart from environmental flow releases. Inflows would be captured up to FSL after which environmental flow releases would cease and flood operation procedures would be implemented.

1.2.1.2 Flood operation

During large rainfall events when the storage level rises above FSL, flood operations mode would commence. In this mode, flood inflows to Lake Burragorang would be captured and temporarily stored (increasing water levels in Lake Burragorang and upstream tributaries). The raised dam would provide capacity (the FMZ) to temporarily capture flood waters during a flood event.

Water would be discharged in a controlled manner via the gated conduits or slots until the dam level returns to FSL. Operating protocols would guide this process and would be developed for approval by the relevant regulatory authorities.

The raised dam would not be able to fully capture inflows from all floods. For floods that exceed the capacity of the FMZ, water would spill firstly over the central spillway and then, depending on the size of the flood, the auxiliary spillway.

For more information on downstream and upstream impacts and benefits from the Project; see Chapter 15 (Flooding and hydrology).

Figure 1-1. Existing operation of the dam

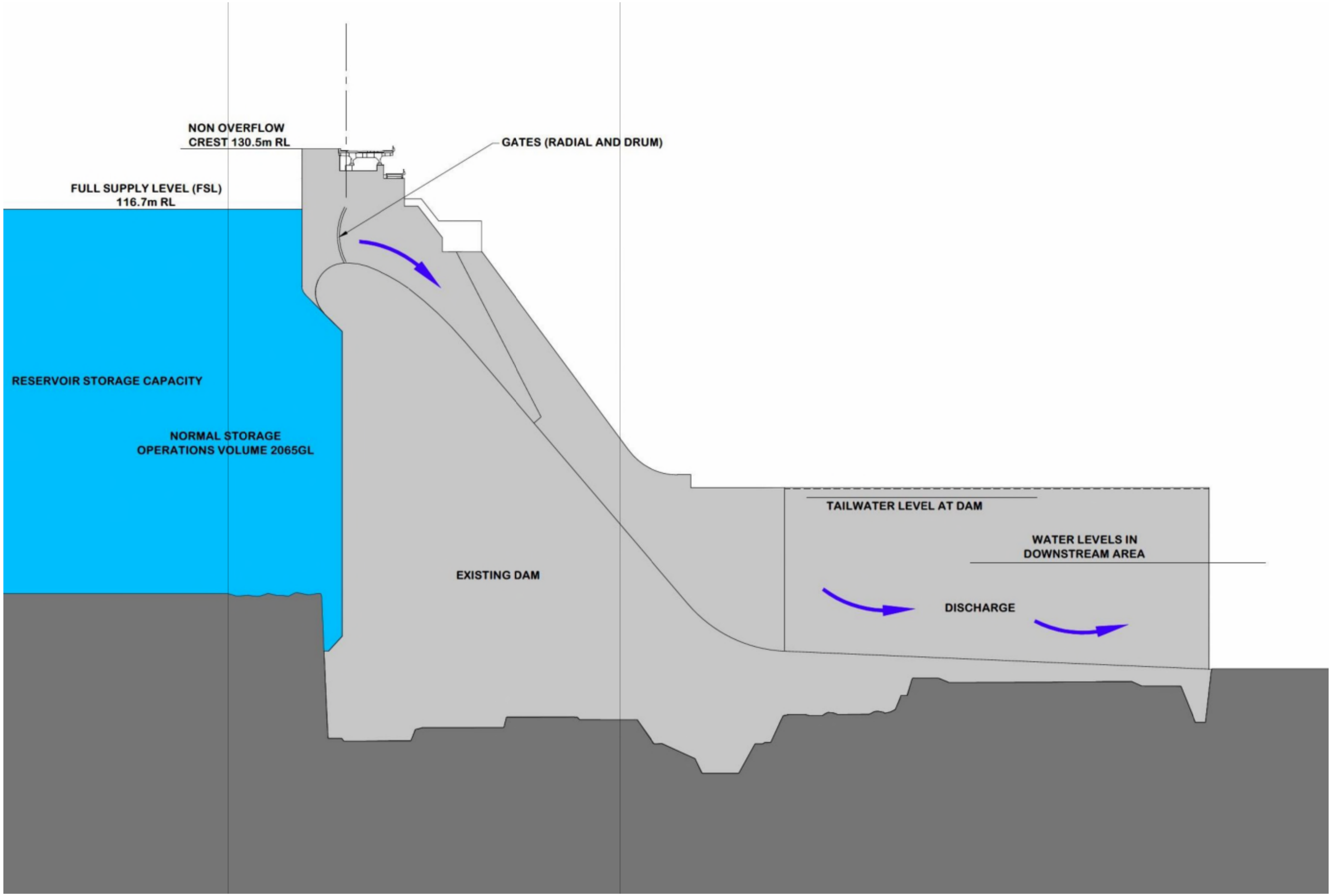
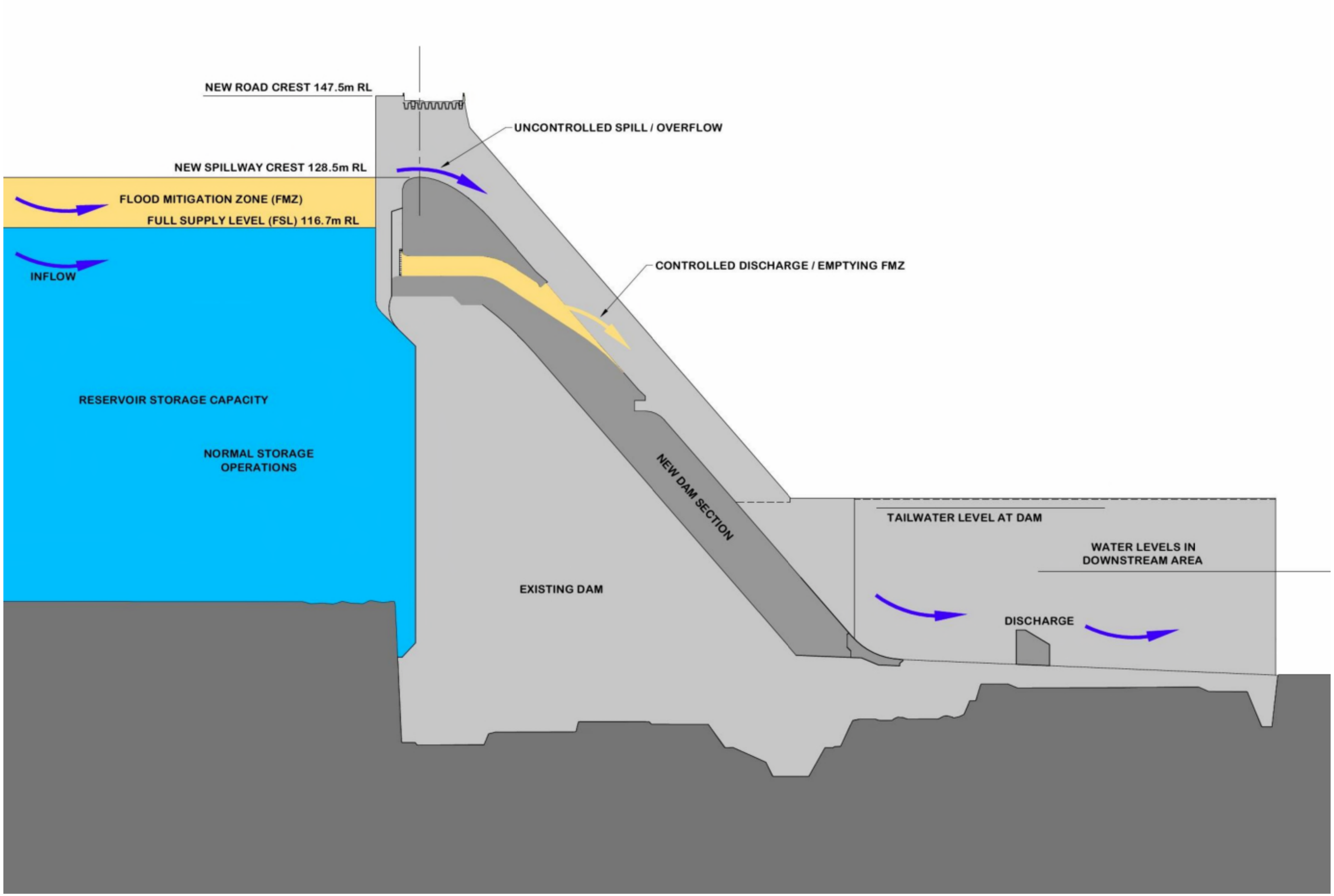


Figure 1-2. Future operation of the dam

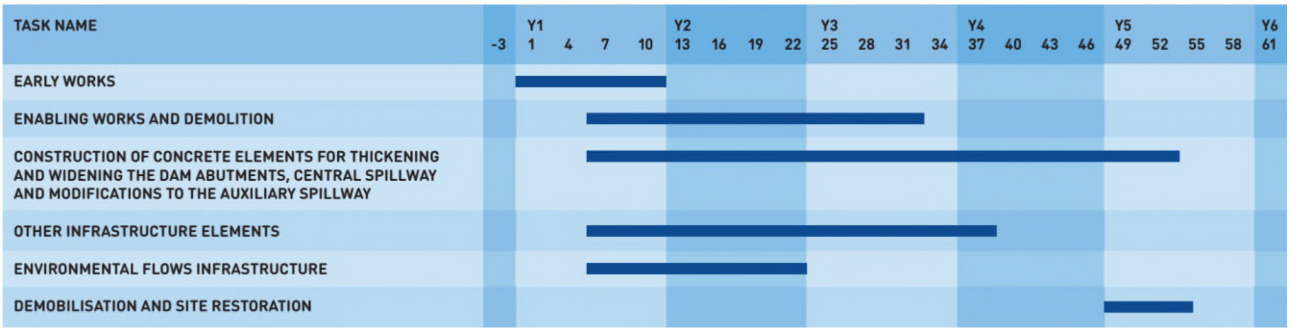


1.2.2 Project construction

This section describes the proposed approach to construction. If the Project is approved, further detailed construction planning would take place prior to commencement to inform a construction environmental management plan (CEMP). This plan would consider methods and the scheduling of activities to minimise impacts on the community and the environment such as noise, access and amenity, and would detail mitigation and management measures.

A preliminary construction program is presented in Figure 1-3 with the Project anticipated to be completed between four to five years from commencement.

Figure 1-3. Preliminary construction program



The number of workers would vary over the program. Up to 300 workers would undertake establishment activities including setting up offices and compounds, assembling the concrete batch plants and beginning early and enabling works. The number of workers on site would increase during construction to around 500 during peak construction periods.

The majority of works would take place during recommended standard construction hours for NSW which are:

- 7 am to 6 pm – Monday to Friday
- 8 am to 1 pm – Saturday
- no work on Sundays and Public Holidays.

This includes the majority of high noise generating activities such as:

- deliveries of materials including concrete, sand and aggregates for concrete production
- demolition work including hydro-blasting (a concrete removal technique that uses high pressure water)
- earthworks, excavations, drilling and blasting.

Some activities would need to take place outside of standard construction hours**.** These activities may include:

- Operation of chilled water plants for cooling and curing of concrete. Continuous cooling of the concrete is required to ensure that heat does not become excessive, and cause cracking and loss of strength of the concrete, during curing.
- Operation of the batching plants for the delivery and pouring of concrete. In warmer periods, concrete pours may not be able to take place in normal working hours. High temperatures may cause thermal issues and cracking during the curing process. Concrete pours may be required at night-time when temperatures are lower.
- Preparatory or emergency works for a flood during the construction period including removing equipment and materials from the construction area, minor earthworks and other activities.
- Work outside the nominated working hours may need to occur in the case of emergencies, delivery of over-sized items or unexpected issues.
- The local community would be notified of construction activities including any activities taking place outside of standard construction hours in accordance with the Community Consultation Plan developed by the construction contractor.

1.3 Scope of this assessment

This report provides an assessment of the vulnerability of the Project to potential impacts from climate change and specifically addresses SEAR 7 as discussed in Section 1.1.

This assessment has considered the impact of *relevant* climate projections on the Project, rather than the impact of the Project on future climate change. The relevance of climate variables to risk to the Project were determined through an initial risk screening, as per Australian Government's *Climate Change Impacts and Risk Management – A Guide for Business and Management* (Department of the Environment and Heritage 2006). The screening results, presented in Section 5.1, determined that the following climate variables were relevant to the Project:

- extreme heat – hot days, heatwaves
- flood producing rains – for example, east coast lows
- 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 was *not* the purpose of this assessment. Flood risk of the Hawkesbury-Nepean Valley was assessed by WMAwater (2019), with relevant information used to inform the need for the Project, feasible options, as well as various sections of the EIS.

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 Section 3.

The risk assessment only considered activities or outcomes that the proponent had ownership, direct control or influence of. Impacts of climate change to activities or outcomes out of the projects 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 were considered in separate technical specialist reports and sections of the EIS.

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 (refer Figure 2-2).

2 Existing environment

2.1 Warragamba Dam and catchment

Warragamba Dam is in a narrow gorge on the Warragamba River, at the foot of the Blue Mountains National Park, about 65 kilometres to the west of the Sydney CBD (Figure 2-1). The damming of Warragamba River, completed in 1960, flooded the Burragorang Valley, creating Lake Burragorang. The lake's capacity is four times that of Sydney Harbour and provides about 80 percent of Sydney's water supply (WaterNSW, 2018a). At present the dam is 142 metres high and 351 metres in length, which makes it one of the largest domestic water supply dams in the world (WaterNSW, 2018a). The Warragamba Dam catchment represents 80 percent of the total Hawkesbury-Nepean catchment at Penrith and 70 percent of the total catchment at Windsor (Infrastructure NSW 2017).

2.2 Hawkesbury-Nepean catchment

The Hawkesbury-Nepean catchment covers an area of about 21,400 square kilometres (refer Figure 2-2). (Department of Environment, Climate Change and Water (DECCW) 2010b). For the purposes of this assessment the catchment was divided into two study areas: upstream (of Warragamba Dam) and downstream.

The upstream study area contains five rivers: the Coxs, Kowmung, Wollondilly, Nattai and Kedumba Rivers (and their tributaries). The downstream study area has five rivers and four major creeks: the Hawkesbury, Nepean, Grose, Colo, and Macdonald Rivers, and Erskine, Webbs, South, and Cattai Creeks.

2.3 Landform and topography

The upstream catchment has unique topographic features, including extensive dissected sandstone plateaux; the most extensive sandstone canyon system in eastern Australia; karst landscapes with several cave systems of importance; prominent basalt-capped peaks and other significant features associated with periods of volcanic activity; quaternary alluvial deposits which support significant heath and woodland vegetation; perched perennial freshwater lakes, and; steep, narrow valleys surrounding watercourses (GHD 2016). The upstream catchment generally consists of deep sandstone gorges surrounding the six major rivers, which reach the escarpment via a single tributary, the Warragamba River.

The topography downstream from Warragamba Dam consists of floodplains, undulating valleys, narrow constrained gorges at confluences of major rivers, as well as along the Hawkesbury and Lower Hawkesbury Rivers downstream from Sackville. Below the escarpment (and dam wall) the Warragamba River meets the Nepean River, which crosses the mid-catchment floodplain. Erskine Creek and the Grose River enter the Nepean River to the south of Richmond, just before the point at which the Nepean River meets the Hawkesbury River. From Richmond, the Hawkesbury River flows across the floodplain through Windsor, where South Creek enters, until it reaches the first narrow sandstone gorge of the downstream catchment at Sackville. From Sackville, the Hawkesbury River winds through the narrow gorges of the downstream catchment, along the way joined by Webb Creek and the Colo and MacDonald Rivers, before it opens out at Broken Bay. This contrasts with other coastal floodplains and river valleys, which tend to progressively widen as the river approaches the estuary.

2.4 Land use

Land-use in the upstream catchment predominantly comprises protected areas, including several national parks (Blue Mountains, Kanangra-Boyd, Nattai), state conservation areas (Jenolan Karst, Yerranderie, Nattai, Burragorang), and 'Special' and 'Controlled' Areas declared under the *Water NSW Act 2014*. Many of these protected areas are within the Greater Blue Mountains World Heritage Area. Minor land uses adjacent to protected areas include urban development, tourism facilities, grazing, forestry, agriculture, manufacturing and mining.

Land-use in the downstream study area is dominated by urban development, commercial and manufacturing services, with protected areas in the north and east of the study area.

Figure 2-1. Warragamba Dam Project study area

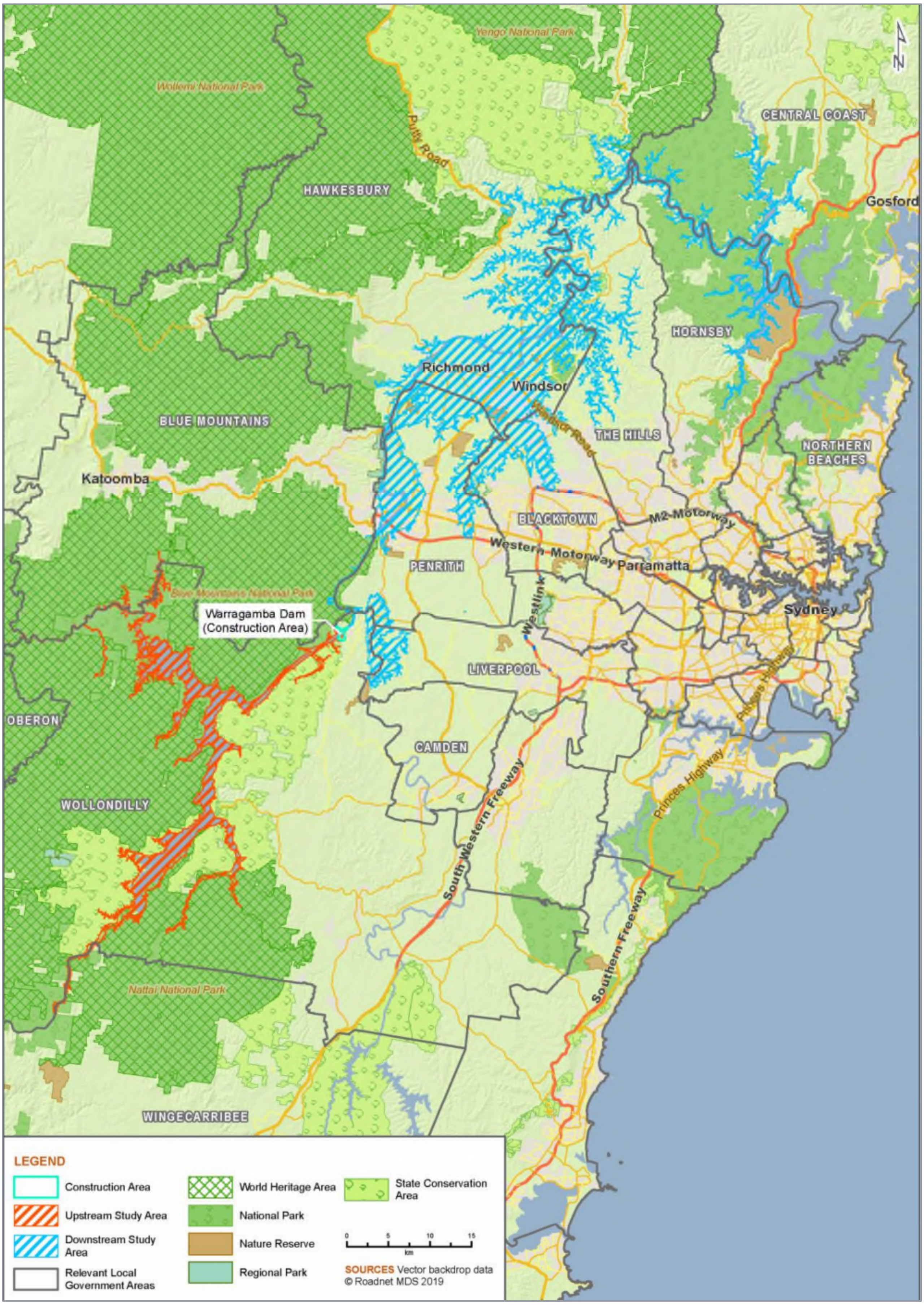
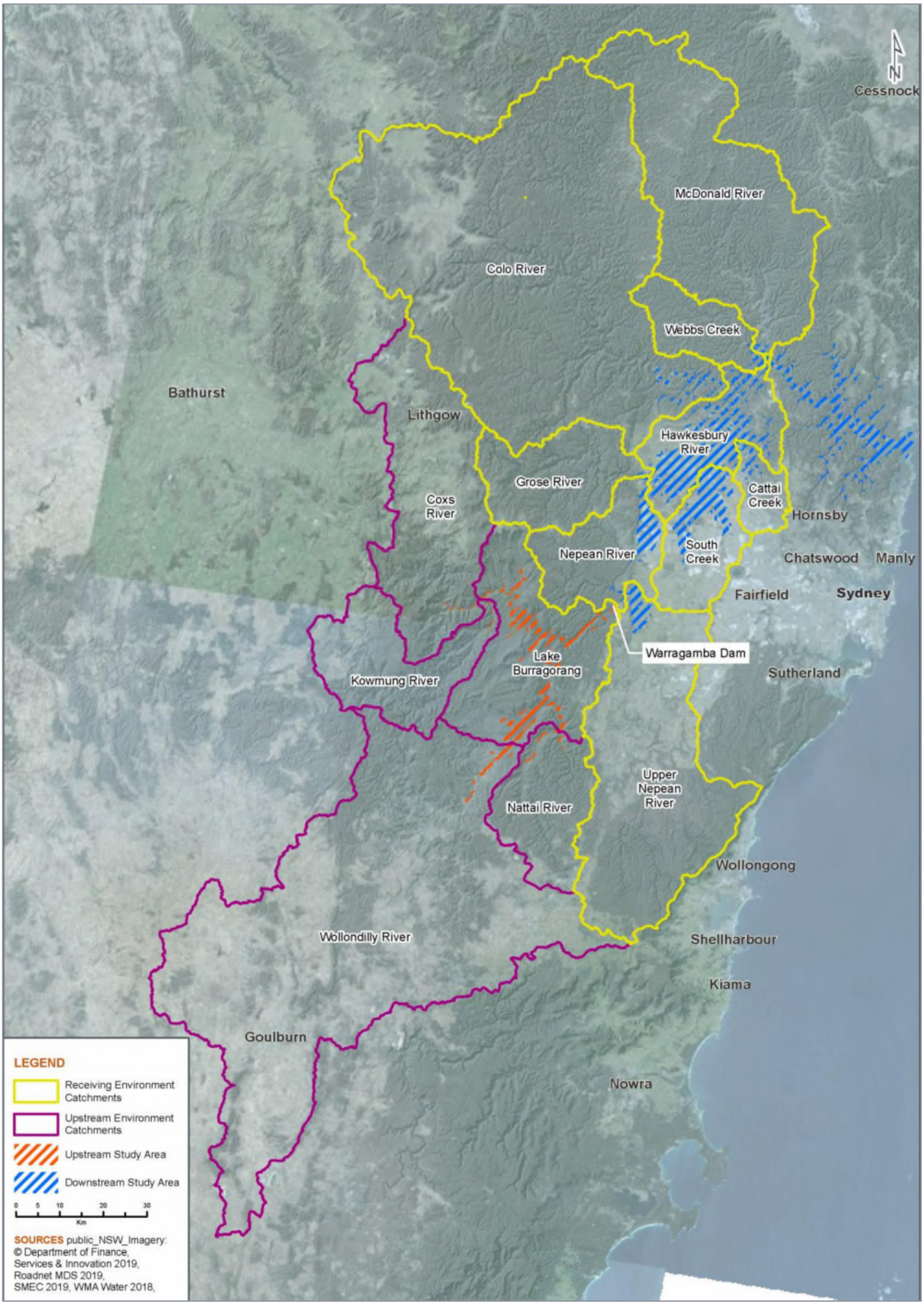


Figure 2-2. Hawkesbury-Nepean catchment



2.5 Socio-economics and demographics

The socio-economic and demographic landscape differs greatly between the upstream and downstream study areas. The main socio-economic values of the upstream study area relate to tourist/recreational opportunities provided by the natural wilderness, including bushwalking. As most of the upstream area is within the Warragamba Dam Special Area, walking tracks are limited to the Katoomba to Mittagong walking trail. Warragamba Dam itself is one of the largest domestic water supply dams in the world, supplying up to 80 percent of Sydney's water (WaterNSW 2015a). This makes the dam of critical socio-economic value.

The downstream study area falls mainly within four Local Government Areas – Penrith City, Hawkesbury City, The Hills Shire, and Blacktown City – and includes the key population centres of Penrith, Richmond and Windsor, plus many surrounding suburbs. The estimated population within the current designated Hawkesbury-Nepean Valley floodplain is up to about 134,000 people, including about 61,100 within the Richmond-Windsor floodplain, and about 49,100 within the Penrith floodplain (Newgate Research 2018, cited in Infrastructure NSW 2019). This population generally has a low perceived flood-risk, limited flood experience, and low levels of preparedness. The downstream catchment represents one of Australia's most diverse and significant economies, with annual gross regional product of about $104 billion in 2013/2014.

The Hawkesbury-Nepean River is a major recreational resource within Western Sydney, with passive riverside recreation the dominant activity. This has been recognised in several Council planning approaches. Industrial and commercial activities also occur within the downstream study area, including commercial fishing, agriculture and tourism. Agriculture is a significant industry, including citrus orchards, market gardens, turf farms and fodder crops, relying predominantly upon rainfall, supplemented with water extracted from the river for irrigation purposes. This provides significant employment opportunities and economic outputs for the region. Commercial fishing (largely in the lower-estuary) comprises the harvesting of school prawn (*Metapenaeus macleayi*), greasyback prawn (*M. bennettae*), eastern king prawn (*Penaeus plebejus*), squid and eels.

2.6 Historical temperature and rainfall

The Hawkesbury-Nepean catchment covers 21,400 square kilometres and extends from Turimetta Headland/ 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 the river mouth, elevation changes by about 1,290 metres. This contrasting elevation and landscapes present significant variations in climate and weather conditions across the catchment.

As such, historical and existing temperature and rainfall observations were summarised from Bureau of Meteorology (BoM) weather stations across the catchment (Table 2-1) to highlight the extremes that occur.

Table 2-1. Weather stations referenced for this assessment

Station name	BoM station no.	Data range	Latitude/longitude	Elevation (m)
Oberon (Springbank)	063063	1946 to 2018	33.67 °S/149.83 °E	1,053
Katoomba (Murri St)	063039	1907 to 2018	33.71°S/150.31 °E	1,015
Goulburn TAFE	070263	1971 to 2018	34.75°S/149.70 °E	670
Penrith Lakes	067113	1995 to 2018	33.72°S/150.68 °E	25
Richmond RAAF	067105	1993 to 2018	33.60°S/150.78 °E	19
Nullo Mountain	062100	1991 to 2018	32.72°S/150.23 °E	1,130
Gosford Narara RS	061087	1954 to 2013	33.39°S/151.33 °E	20

2.6.1 Summary of historic temperature observations

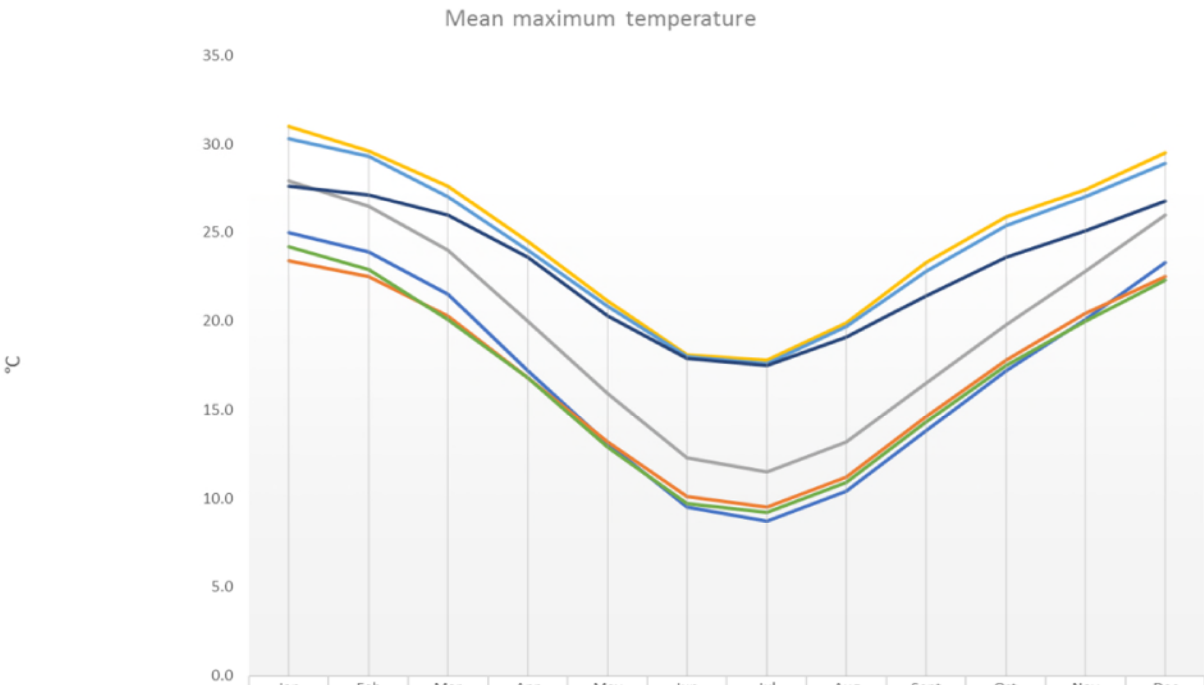
Temperature averages across the catchment display significant temporal and spatial variation. January is the hottest month, with mean maximum temperatures ranging from 23.4 °C at Katoomba to 31.0 °C at Penrith Lakes. The coldest month is July with mean maximum temperatures ranging from 8.7 °C at Oberon to 17.8 °C at Penrith Lakes (Figure 2-3).

Mean minimum temperatures are warmest in January (Goulburn, Penrith Lakes, Nullo Mountain) and February (Oberon, Katoomba, Richmond RAAF, Gosford) with temperatures ranging between 11.2 °C at Oberon and 18.6 °C at Penrith Lakes. Mean minimum temperatures are coolest in July, ranging between -0.3 °C at Oberon and 5.4 °C at Penrith Lakes (Figure 2-4).

2.6.2 Summary of historic rainfall observations

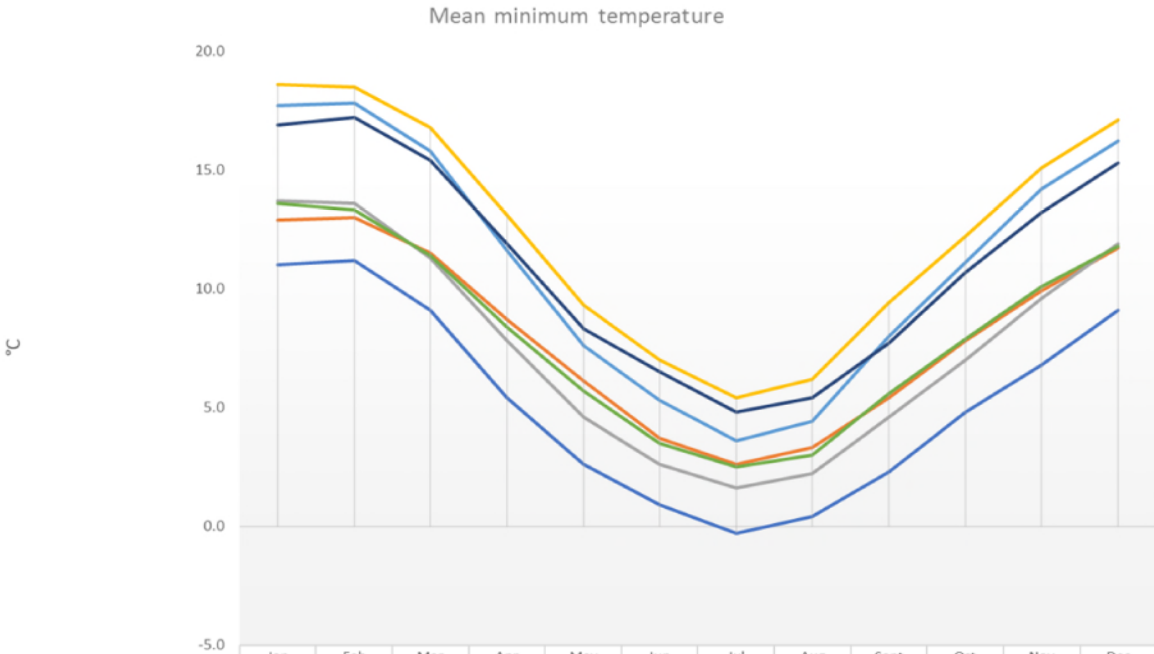
The changes in topography and elevation across the catchment result in significant differences in rainfall. Mean average annual rainfall ranges from 1,401.9 millimetres at Katoomba to 624.6 millimetres at Goulburn. January to March are generally the wettest months, while July to September are generally the driest months (Figure 2-5). Further, detailed analysis of existing and historical rainfall for the study area is provided by WMAwater (2019).

Figure 2-3. Mean maximum temperature for the study area



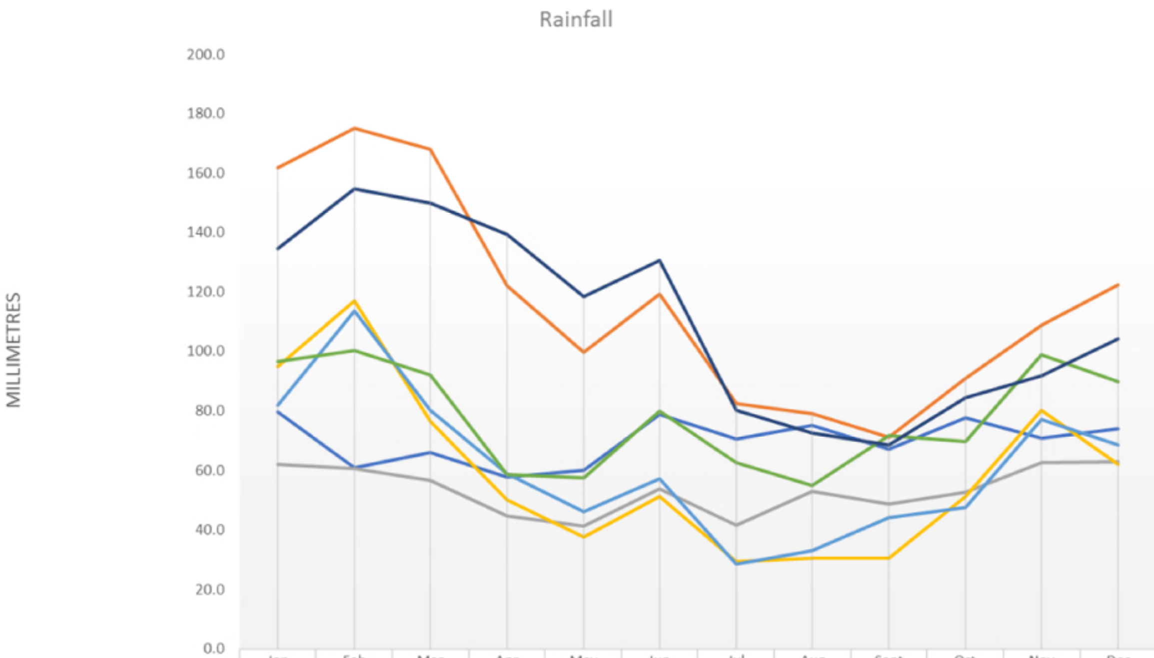
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Oberon (1946-2018)	25.0	23.9	21.5	17.2	13.1	9.5	8.7	10.4	13.8	17.2	20.1	23.3
Katoomba (1907-2018)	23.4	22.5	20.3	16.8	13.2	10.1	9.5	11.2	14.6	17.8	20.4	22.5
Goulburn TAFE (1971-2018)	27.9	26.5	24.0	20.0	15.9	12.3	11.5	13.2	16.5	19.8	22.8	26.0
Penrith Lakes (1995-2018)	31.0	29.6	27.6	24.5	21.1	18.1	17.8	19.9	23.3	25.9	27.4	29.5
Richmond RAAF (1993-2018)	30.3	29.3	27.0	24.0	20.8	18.0	17.6	19.7	22.8	25.4	27.0	28.9
Nullo Mountain (1991-2018)	24.2	22.9	20.1	16.8	12.9	9.7	9.2	10.9	14.3	17.5	20.0	22.3
Gosford (1954-2013)	27.6	27.1	26.0	23.6	20.3	17.9	17.5	19.1	21.4	23.6	25.1	26.8

Figure 2-4. Mean minimum temperature for the study area



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Oberon (1946-2018)	11.0	11.2	9.1	5.4	2.6	0.9	-0.3	0.4	2.3	4.8	6.8	9.1
Katoomba (1907-2018)	12.9	13.0	11.5	8.7	6.1	3.7	2.6	3.3	5.4	7.8	9.9	11.7
Goulburn TAFE (1971-2018)	13.7	13.6	11.3	7.8	4.6	2.6	1.6	2.2	4.6	7.0	9.6	11.9
Penrith Lakes (1995-2018)	18.6	18.5	16.8	13.1	9.3	7.0	5.4	6.2	9.4	12.2	15.1	17.1
Richmond RAAF (1993-2018)	17.7	17.8	15.8	11.6	7.6	5.3	3.6	4.4	8.0	11.1	14.2	16.2
Nullo Mountain (1991-2018)	13.6	13.3	11.4	8.4	5.7	3.5	2.5	3.0	5.6	7.9	10.1	11.8
Gosford (1954-2010)	16.9	17.2	15.4	11.9	8.3	6.5	4.8	5.4	7.7	10.7	13.2	15.3

Figure 2-5. Mean monthly rainfall for the study area



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Oberon (1888-2018)	79.6	60.8	65.9	57.7	60.0	78.6	70.6	75.0	67.2	77.6	70.7	73.9
Katoomba (1885-2018)	161.9	175.0	168.1	122.1	99.6	119.4	82.3	79.1	71.0	90.8	108.8	122.4
Goulburn TAFE (1971-2018)	61.9	60.7	56.7	44.6	41.2	53.7	41.6	53.0	48.6	52.7	62.6	62.8
Penrith Lakes (1995-2018)	94.8	116.9	76.5	50.1	37.5	51.3	29.3	30.4	30.6	51.3	80.0	62.0
Richmond RAAF (1994-2018)	81.7	113.7	80.1	59.0	46.1	57.2	28.4	33.1	44.2	47.5	77.0	68.6
Nullo Mountain (1994-2018)	96.7	100.2	91.9	58.6	57.5	79.8	62.5	54.8	71.6	69.5	98.9	89.7
Gosford (1916-2013)	134.7	154.7	149.9	139.4	118.3	130.5	80.2	72.4	68.5	84.5	91.7	104.2

2.7 Historical extreme weather and climate events

Extreme weather or climate events are defined as 'an occurrence of a value of weather or climate variable beyond a threshold that lies near the end of the range of observations for the variable' (Intergovernmental Panel on Climate Change (IPCC) 2012). These events historically occur only rarely, differ markedly from usual weather and climate patterns, and are often associated with adverse impacts on society or the environment. Extreme weather events are generally acute – short-lived, abrupt events that are 'shocks' within the climate system. Extreme climate events generally last much longer and are more intense (Climate Council 2017a). The main extreme weather and climate events that affect the greater Sydney area are extreme rainfall and flooding associated with east coast lows, extreme heat and heatwaves, and fire weather.

2.7.1 East coast lows and extreme rainfall/flooding

Mid-latitude cyclones, known as East Coast Lows (ECLs), are one of the most important climatic features of Australia's east coast. They occur on average 10 times a year and are more common during winter (Callaghan and Power 2014). These events produce high-intensity rainfall and thus are critically important for influencing annual rainfall totals and for water security (Pepler and Rakich 2010). Conversely, they are also responsible for most major east-coast floods (Callaghan and Power 2014)[2]. Although it is important to note that not every ECL has resulted in a flood, the following major floods in the Hawkesbury-Nepean catchment were attributed to ECLs: 1867, 1869, 1870, 1873, 1878, 1879, 1900, 1904, 1913, 1914, 1917, 1925, 1930, 1931, 1933, 1938, 1943, 1950, 1952, 1956, 1959, 1961, 1964, 1978, 1984, 1986, 1987, 1988, 1995, and 1998 (Callaghan and Power 2014).

2.7.2 Hot days and heatwaves

Extreme hot days (>35 °C) in Sydney currently average fewer than 10 per year, largely due to proximity to the coast. However, areas in western Sydney (including most of the study area) experience 10 to 20 hot days on average per year (Office of Environment and Heritage (OEH) 2014).

2.7.3 Fire weather

In NSW, the Forest Fire Danger Index (FFDI) is used to define fire weather. This index combines observations for temperature, humidity, and wind speed, with an estimate of the fuel (vegetation) state. The closest FFDI monitoring station to the Project study area is at Richmond; however, it is important to note that this location is not likely to be representative for the Project construction area (that is, Warragamba Dam). The long-term FFDI estimate from Richmond is 7.1 for the period of 1990-2009. FFDI values below 12 indicate low to moderate fire weather. Fire weather is classified as severe when the FFDI is above 50. Severe fire weather conditions are estimated to occur on average 1.8 days per year at Richmond, most likely in summer and spring months.

2.8 Flooding

The Hawkesbury-Nepean Valley has one of the most significant flood risk exposures within Australia. The risk to property and life due to flood exposure is well known and has been the subject of numerous studies, including the *Hawkesbury-Nepean Valley Flood Risk Management Strategy* (Infrastructure NSW 2017), which was prepared on behalf of the NSW State Government. Additional flood modelling was undertaken as part of the Project assessment and outcomes are presented in Appendix H1 (Flooding and hydrology assessment report(to the EIS.

2.8.1 Upstream catchment

Flooding in the upstream catchment is characterised by backwater inundation, with floodwaters building on the upstream side of the dam wall. The water level builds until the outflow exceeds the inflow, at which time the water level recedes to the FSL. The extent and duration of inundation is dependent upon the magnitude of the flood producing rainfall event, the level of Lake Burragorang at the time of the inflow event and the dam release rate. Flood modelling results at the dam wall are shown in Table 2-2 and Figure 2-6. It should be noted that existing peak flood levels may be higher in the upper tributary reaches.

The inundation extent is controlled by the peak flood level at the dam wall and the topography across the upstream catchment. Steep terrain extends upstream from the dam wall for at least 20 kilometres, so that the extent of land

[2] Callaghan and Power (2014) define major floods by (1) if it causes inundation of a river within approximately 50 kilometres of the coast, or (2) if there is non-riverine flooding overland near the coast, from the active part of a weather system, that extends at least 20 kilometres along the coast. Record data range 1860 to 2012.

inundated changes at a relatively small rate with increasing magnitude floods. However, the rate of change and inundated area increases as terrain flattens about where the Wollondilly River and Coxs River enter the lake.

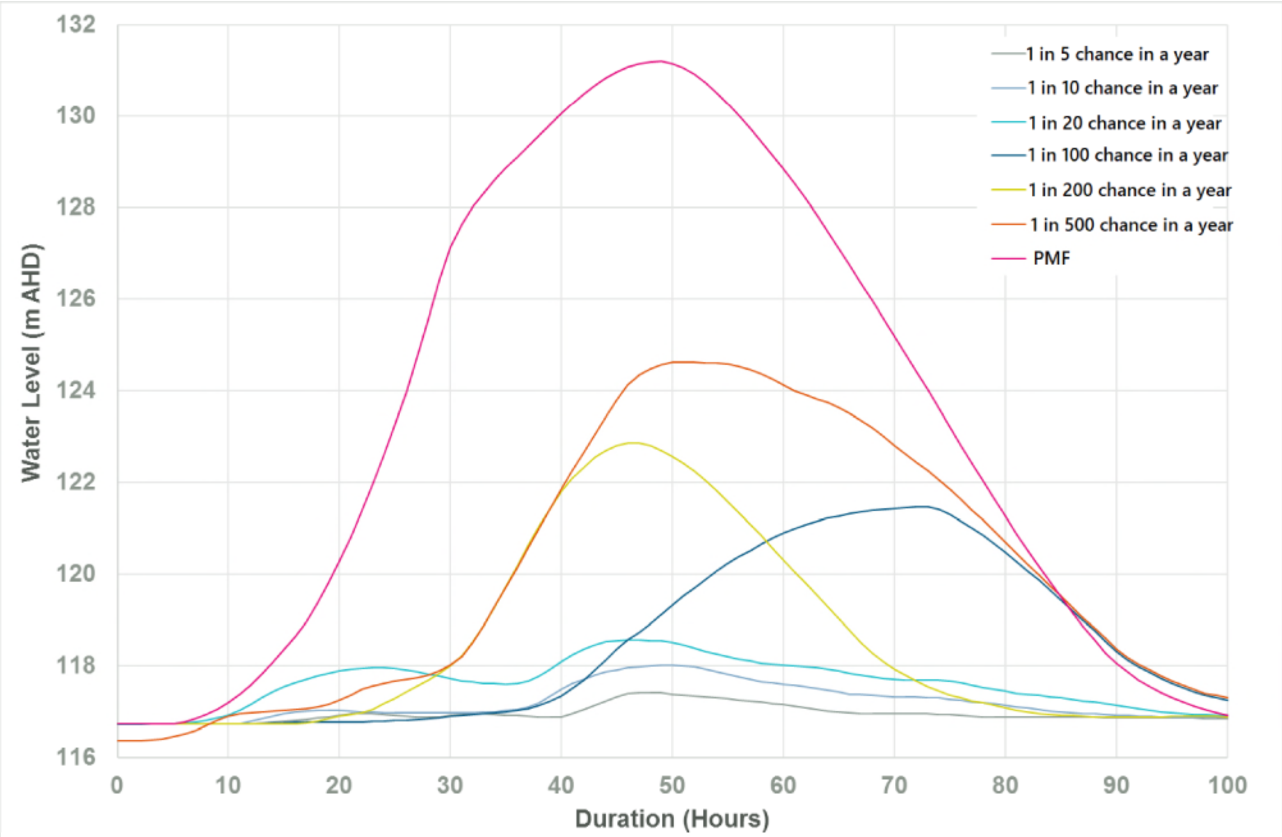
Flood inflows from the upstream catchment into Lake Burragorang result in water levels being elevated for up to several days depending on rainfall and inflow quantity. Important to note is that although lake levels remain elevated for a period of hours to around two weeks, the duration of inundation for specific locations will vary depending on their location in the catchment. It is also important to note that the upstream catchment is already subject to flooding due to the presence of Warragamba Dam, and the focus of the assessment is on the incremental impact presented by the Project.

Flood storage areas are characterised by deep, low velocity floodwaters, although higher velocities would be expected where major tributaries discharge into the lake.

Table 2-2. Upstream peak flood levels

Flood event (1 in X chance in a year)	Water level (RL metres)
5	117.4
10	118.0
20	118.6
100	121.5
200	122.9
500	124.6
Probable Maximum Flood (PMF)	131.2

Figure 2-6. Upstream water level time series at the dam



2.8.2 Downstream catchment

Floodwaters flowing into the Hawkesbury-Nepean Valley come from several different river catchments. The largest of these, representing 80 percent of the catchment at Penrith and 70 percent of the catchment at Windsor, is the Warragamba River catchment, which drains into Lake Burragorang.

Further inflows originate from the Nepean River, the Grose River, South Creek and others. While floods can occur without contribution from the Warragamba catchment, most significant floods (above the 1 in 100 chance in a year flood) would include significant inflows from the Warragamba River catchment. However, each flood event is unique due to the timing of rainfall across the Hawkesbury-Nepean Valley catchment.

Flood modelling was undertaken for existing conditions to determine the extent and impacts of a range of flood events including those greater than 1 in 100 chance in a year event. The biggest flood in the Hawkesbury-Nepean Valley since European settlement occurred in 1867 and this has been estimated to be a 1 in 500 chance in a year flood at Windsor.

The inundation extent is controlled by the topography across the floodplain, with floodwaters primarily contained within the channel and highly incised valley floor for some reaches, and widespread inundation in other sections of the floodplain. There are also significant step changes in inundation extents between flood events, for example the reach of the Nepean River from the dam wall to immediately upstream of Penrith is characterised by steep terrain with a highly incised channel, resulting in a narrow flood extent, while near the regional localities of Penrith, Windsor and Richmond the floodplain is notably flatter and wider, and flood inundation extends over a greater area.

The rate of rise of floodwaters is a function of the dam outflow and local topography. The water level time-series at selected locations within the catchment corresponding to modelled cross sections are presented in Chapter 15 (Flooding and hydrology) of the EIS. The duration of inundation will also vary depending on location within the receiving environment, with water levels typically returning to standard/pre-response levels within six to eight days after the initial response.

Peak flow velocities are relatively consistent across the floodplain, with minimal variation in flow velocity with increasing event magnitude.

Flood characteristics for various flood events are summarised below.

- 1 in 5 chance in a year flood
  - Wallacia: Minor overbank flooding at some locations on the river and increased overbank flooding along many of the tributaries flowing into this section of the river.
  - Penrith: Some over bank flooding in the Penrith Lakes area and at some locations west of the river near Emu Plains. No developed areas would be affected.
  - Windsor and Richmond: Substantial overbank flooding along South Creek and its tributaries. Residential areas in North Richmond, Richmond, Windsor and the North West Growth Centres would generally be flood free. Bridge crossings at Windsor and Richmond would be underwater and impassable.
- 1 in 10 chance in a year flood
  - Wallacia: Some overbank flooding along the river and increased overbank flooding along many of the tributaries flowing into this section of the river.
  - Penrith: Some over bank flooding in the Penrith Lake area and at some locations west of the river near Emu Plains. No developed areas would be affected.
  - Windsor and Richmond: Substantial overbank flooding along South Creek and its tributaries. Residential areas in North Richmond, Richmond, Windsor and the North-West Growth Centres would generally be flood free. Some increased flooding in Riverstone. Bridge crossings at Windsor and Richmond would be underwater and impassable.
- 1 in 20 chance in a year flood
  - Wallacia: Overbank flooding along both sides of the river and substantial overbank flooding along many of the tributaries flowing into this section of the river.
  - Penrith: Some over bank flooding in the Penrith Lake area and at some locations west of the river near Emu Plains. Some residential areas of Emu Plains may experience flooding.
  - Windsor and Richmond: Substantial overbank flooding along South Creek and its tributaries. Residential areas in North Richmond, Richmond, most of Windsor and the North-West Growth Centres would be flood

free. Some increased flooding in South Windsor and Riverstone. Bridge crossings at Windsor and Richmond would be underwater and impassable.

- 1 in 100 chance in a year flood
  - Wallacia: Flooding generally confined to a 7.5 kilometre section of the Nepean River, typically either side of the river channel with minor backwater flooding of minor tributaries to the east of the river. Wallacia town centre would not be affected by flooding, however all connecting roads would be flooded.
  - Penrith, Emu Plains and Penrith Lakes: Some residential areas in Emu Plains would be flooded, however most flooding would be restricted to undeveloped, former sand mining and rural areas. Some industrial facilities and public infrastructure (for example, Emu Plains Correctional Centre and Penrith Sewage Treatment Plant) may be impacted by flooding. There would be minor flooding of the Penrith town centre, however most of the town centre would not be affected.
  - Richmond and North Richmond town centres: Generally, remain flood free, however the fringe areas of both towns may experience some flooding. North Richmond is likely to be isolated. The Bells Line of Road to the north of the town would be inundated and the Richmond Bridge over the Hawkesbury River and Kurrajong Road completely submerged.
  - Other: Apart from the central area of Windsor, substantial areas of Wilberforce, South Windsor, Mulgrave, Pitt Town and McGraths Hill would be flooded. The depth of flooding would generally be greater than 17 metres and there would be significant damage to properties and public infrastructure. Back water flooding would also occur along South Creek and its tributaries potentially impacting Riverstone and Windsor Downs.
- 1 in 500 chance in a year flood
  - Wallacia: About 25 percent of Wallacia would be affected by flooding and all connecting roads would be flooded.
  - Penrith: About 50 percent of Emu Plains and Emu Plains Height would be flooded. Smaller areas of Leonay, Regentville and Jamisontown would also be flooded. All river front land and about a third of the Penrith town centre would be flooded. Large areas of industrial development in Penrith would also be flooded.
  - North Richmond: Generally remains flood free, however some fringing residential areas and the industrial area would be flooded . North Richmond is likely to be isolated. The Bells Line of Road to the north of the town would be inundated and the Richmond Bridge over the Hawkesbury River and Kurrajong Road completely submerged.
  - Richmond: About a third of the residential area would be flooded and a flood island consisting of east Richmond would form. About 80 percent of RAAF Richmond would be underwater.
  - Windsor: About 50 percent of Windsor would be flooded and the remaining unflooded areas would be surrounded by flood waters (that is, would form a flood island), making evacuation via road impossible;
  - Other: All or most of Mulgrave, McGraths Hill, Blighs Park and Pitt Town would be flooded. Unflooded areas in Pitt Town would be surrounded by flood waters (that is, would form a flood island), making evacuation via road impossible
  - Back water flooding: This would also occur along South Creek and its tributaries flooding large areas of Londonderry, Schofields, Marsden Park, Riverstone and Windsor Downs.
- Probable maximum flood (PMF)
  - Wallacia: All the town would be inundated and there would be considerable flood damage. The flooded area would be approximately double that flooded in the 1 in 100 chance in a year event.
  - Leonay, Emu Heights and Emu Plains residential areas: All these areas would be flooded. On the eastern side of the river, the Penrith town centre and some adjacent residential areas, industrial zones and public infrastructure would also be inundated.
  - Richmond and Agnes Banks and large areas of Londonderry and North Richmond: All these areas would be flooded.
  - Wilberforce, Windsor, Bligh Park and McGraths Hill: All these areas would be flooded. The depth of flooding would be significant, for example approximately 26.7 metres at Windsor Bridge, and there would be significant damage to properties and public infrastructure.
  - South Creek: Backwater flooding would occur along South Creek and its tributaries, and inundate Berkshire Park, Shanes Park, Ropes Crossing and parts of St Marys and Werrington.

- Eastern Creek: Flooding would occur on areas in North West Growth Centres along Eastern Creek including Vineyard, Schofields, Riverstone, Marsden Park, Colebee and Quakers Hill.

2.8.3 Flood evacuation

Evacuating people from flood affected areas is the primary method of reducing the risk to life during a flood event. In the Hawkesbury-Nepean Valley, the NSW State Emergency Service (SES) identifies mass self-evacuation by private motor vehicles as the primary method for evacuation, as other transport options are highly vulnerable to floods or have limited capacity. Currently, there is insufficient road capacity to safely evacuate the whole population in time, with multiple communities relying on common, constrained and congested road links as their means of evacuation.

The undulating topography of the Hawkesbury-Nepean Valley results in many key evacuation routes becoming flooded at low points long before population centres are inundated, creating flood islands. Many of the significant urban centres such as McGraths Hill, Windsor, Richmond and Bligh Park are located on flood islands, which can become fully submerged in large flood events.

Reliable and timely flood forecasts and warnings are critical for evacuation. Currently the BoM has advised that it can provide up to 15-hour flood level predictions for large flood events. However, the SES requires more than 15 hours to evacuate some flood islands in the Hawkesbury-Nepean Valley during large flood events. This could force the SES to make evacuation orders based on uncertain flood prediction. If the flood exceeds the prediction, lives could be at risk. Alternatively, if the flood does not reach the predicted level, large numbers of people could be evacuated unnecessarily, which could mean people may be reluctant to follow future evacuation orders.

If a 1 in 100 chance in a year flood occurred today, more than 64,000 people would need to evacuate. This could rise to 90,000 people for a 1 in 500 chance in a year flood.

2.8.4 Flood management

Local governments are required to prepare floodplain risk management plans based upon guidance in the *Floodplain Development Manual* (DIPNR 2005) and the *Flood Prone Land Policy*. The primary objective of the Flood Prone Land Policy is to reduce the impacts of flooding and flood liability on individual owners of flood prone property, and to reduce private and public losses resulting from floods.

The key outputs from the Floodplain Risk Management Plan are:

- local mitigation measures to reduce flooding impact (for example, levees)
- planning controls – which are generally flood levels below which flood sensitive development is not permitted
- flood warning, readiness and response planning
- environmental programs which may reduce flooding (for example, wetland restoration)
- monitoring and date collection programs.

The Hawkesbury-Nepean Valley Flood Risk Management Strategy was guided by the *Floodplain Development Manual* (DIPNR 2005) and the *Flood Prone Land Policy*. It contains the key outputs required for a regional Floodplain Risk Management Plan; which would supersede local floodplain risk management plans, where appropriate.

2.9 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) 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, and early 21st-century (Intergovernmental Panel on Climate Change 2014). This warming pattern was near universal across the globe (IPCC 2013a). Globally averaged air temperatures have warmed by 1 °C since records began in 1850, and each of the last four decades have been warmer than the previous (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 2013a, BoM 2017a).

Atmospheric concentrations of certain major long-lived atmospheric 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 ppm, 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 (Office of Environment and Heritage 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 (Figure 2-7) (BoM 2017). Sea surface temperatures have warmed by nearly 1 °C since 1910, with the past seven years in the top ten warmest on record (Figure 2-8) (BoM 2017a). 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) (Figure 2-9).

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 – for example, extreme heat, bushfires, drought, extreme rainfall, 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 2017a).

Figure 2-7. Long-term annual temperature anomaly, Australia (BoM 2017a)

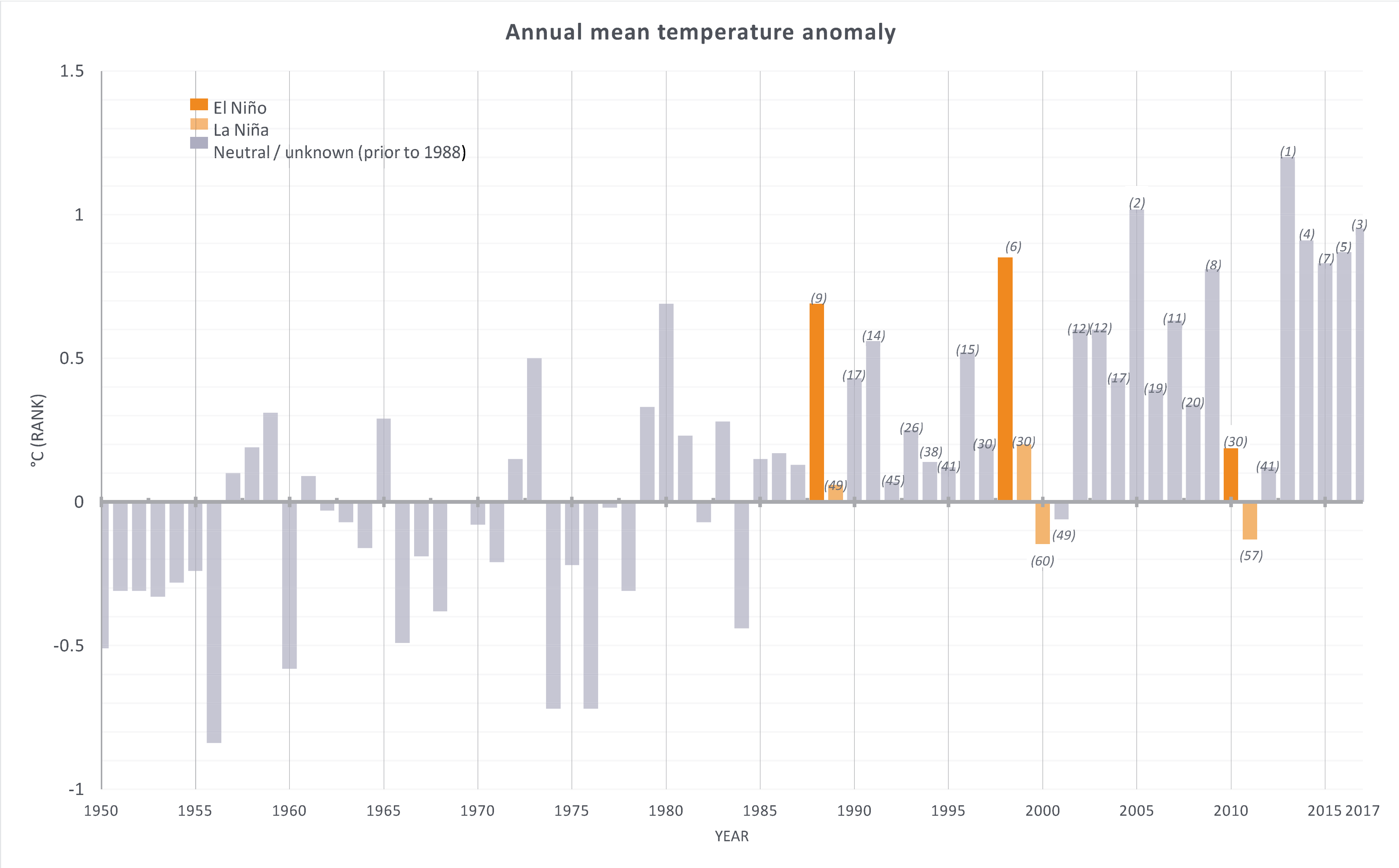


Figure 2-8. Long-term annual sea-surface temperature anomaly, Australian region (BoM 2017a)

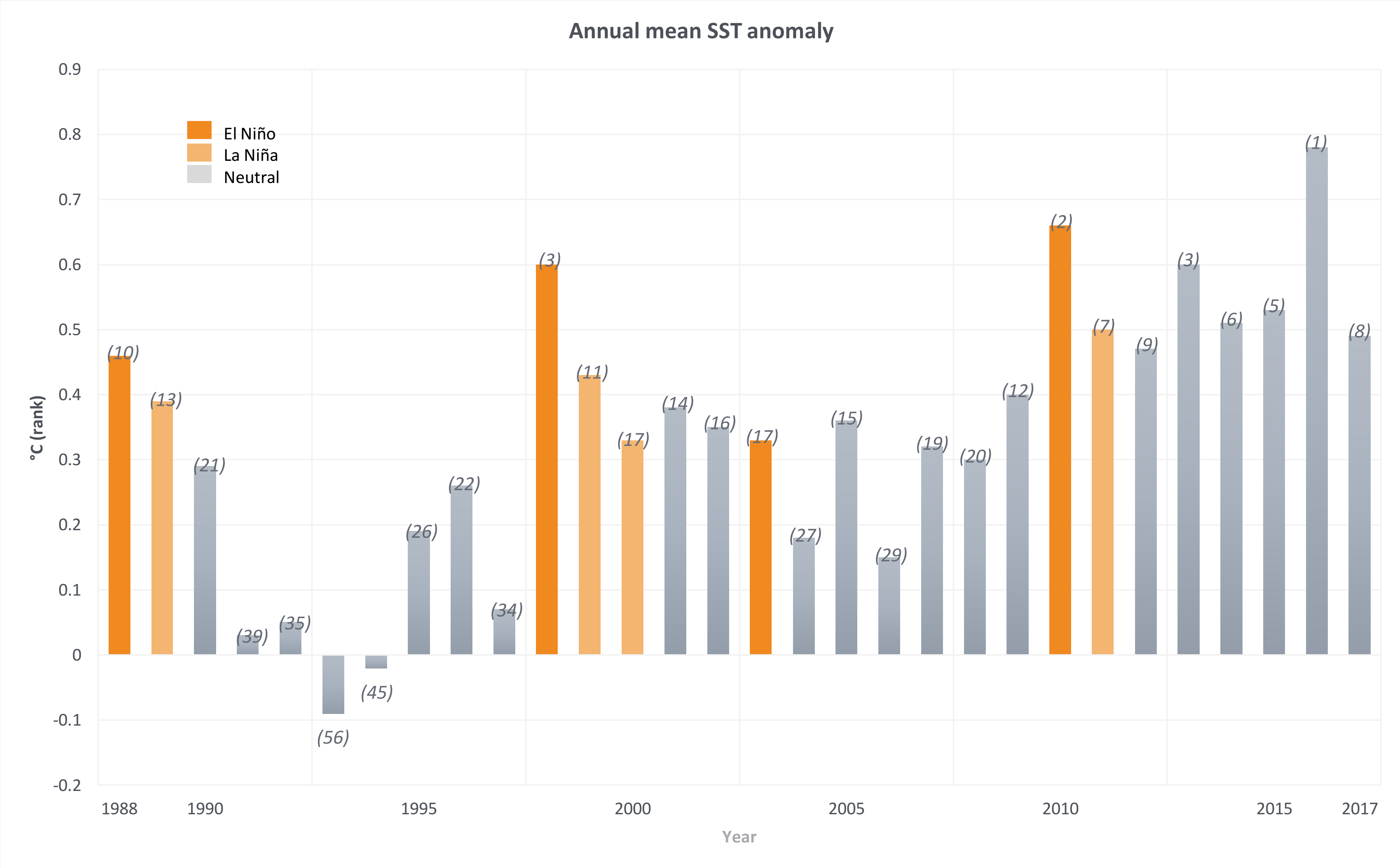
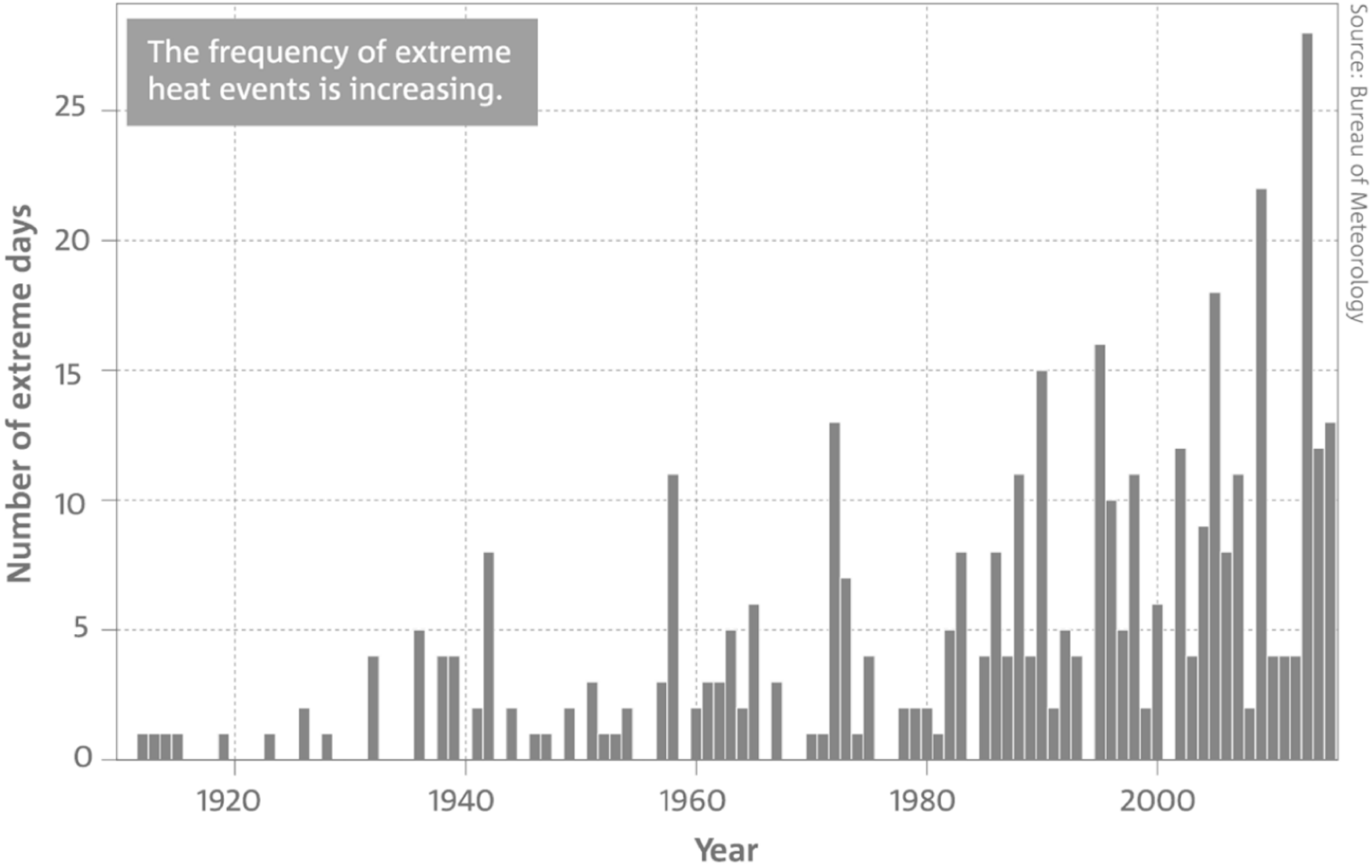


Figure 2-9. Trend in extreme temperature days, Australia (source: BoM 2017a)



3 Climate projections

There is overwhelming scientific consensus that the climate is warming, and many of the observed climate changes since the 1950s are unprecedented over decades to millennia (National Aeronautics and Space Administration (NASA) 2018). For example, surface temperature observations of each of the last three decades have been successively warmer than any preceding decade since the 1850s (IPCC 2013a).

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

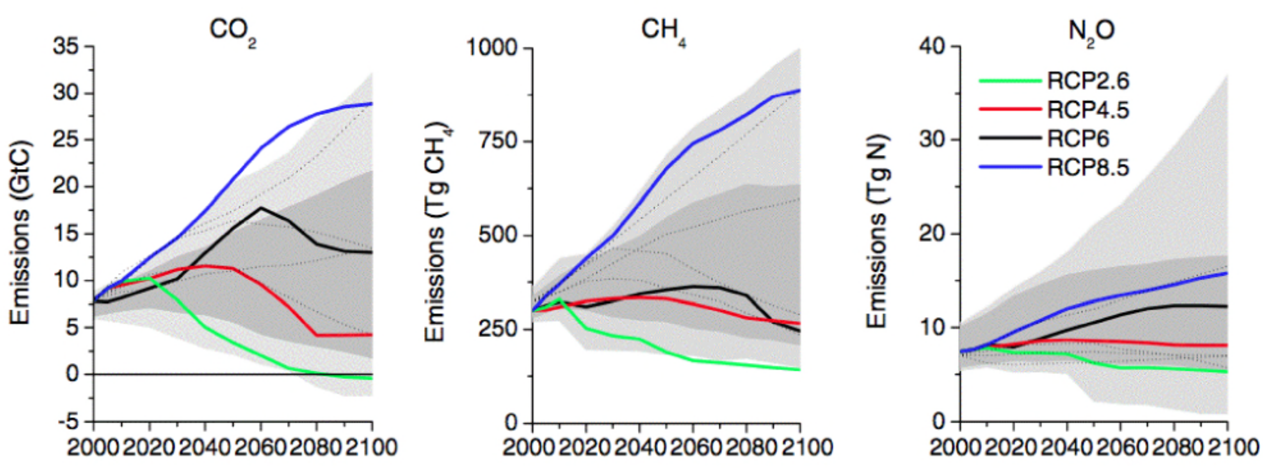
3.1 Intergovernmental Panel on Climate Change

The IPCC produces assessment reports which review and synthesise the current (as at the time of each report's publication) 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 2013a). RCPs were developed to represent possible future emissions and concentrations 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" (DoE 2013).

AR5 presents four RCPs – RCP8.5, RCP6, RCP4.5, and RCP 2.6 (the last is also referred to as RCP3-PD, where PD stands for peak and decline). The numbers associated with each RCP are the amount of radiative forcing produced by greenhouse gases in 2100. Radiative forcing is a measure of the energy absorbed and retained in earths lower atmosphere – "effectively a measure of the amount the Earth's energy budget is out of balance" (DoE 2013). Radiative forcing can be positive, representing heating, or negative, representing cooling, and is affected by atmospheric greenhouse gas and aerosol concentrations, changes in land-cover and natural drivers (for example, total solar irradiance).

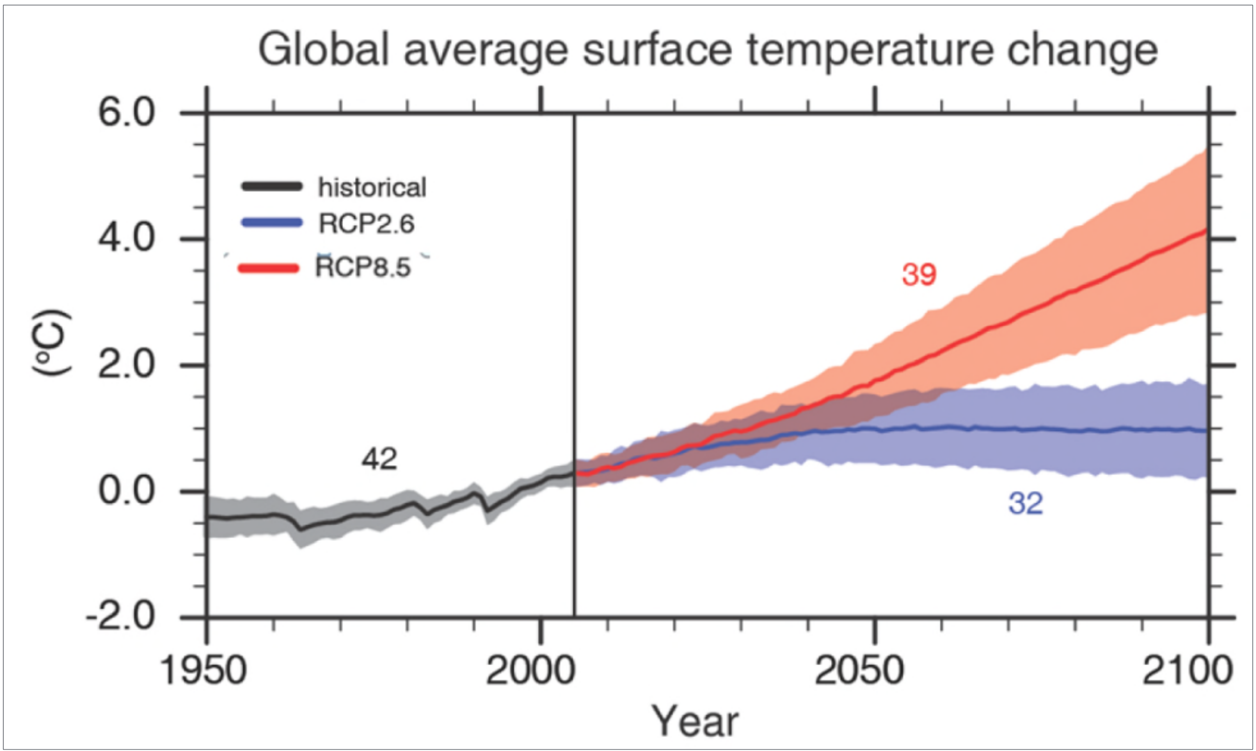
Each RCP presented in AR5 defines a specific emissions trajectory and subsequent radiative forcing, and explicitly include the effect of mitigation. Trajectories for three main greenhouse gases – carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) – are shown in Figure 3-1.

Figure 3-1. Emissions of main greenhouse gases across RCPs. Grey area indicates the 98th and 90th percentiles of the literature referenced in AR5. The dotted line represents scenarios used in AR4. The x-axis represents years.



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 3-2.

Figure 3-2. AR5 global average surface temperature change. 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.



The AR5 (IPCC 2013b) summary snapshot for the Australian and New Zealand region states that regardless of RCP:

- Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system.
- Warming is projected to continue through the 21st century along with other changes in climate, including:
  - rising snow lines
  - more frequent hot extremes, less frequent cold extremes
  - increasing extreme rainfall related to flood risk
  - increased intensity of tropical cyclones
  - increase in fire weather
  - regional sea-level would exceed the historical rate (1971-2010), consistent with global trends.
- The uncertainty in projected rainfall changes remains large for the south-east of Australia.
- There are projected increased frequency and intensity of extreme climatic events (for example, flood, drought, heat wave, bushfire) with significant vulnerability for some ecosystems and many human systems.
- Without adaptation, further changes in climate, atmospheric CO_2, and ocean acidity are projected to have substantial impacts on water resources, coastal ecosystems, infrastructure, health, agriculture, and biodiversity.
- The projected climate changes may result in increased frequency and intensity of flood damage to settlements and infrastructure in Australia and New Zealand.

The horizontal spatial resolution of AR5 projections is 70 to 200 kilometres.

3.2 Project relevant climate projections

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 similar and applies it to the Weather Research and Forecasting (WRF) model to develop high-resolution models for meteorological variables

- Centre for Australian Weather and Climate Research Projections - a collaboration between CSIRO and the BoM, which developed the Australian Community Climate and Earth-System Simulator, available through *Climate Change in Australia* (Department of the Environment and Heritage (DEH) 2018). 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 (DECCW 2010a) provides climate projections for a single, high-emissions scenario.

The NARCLiM projections compliment those provided through Climate Change in Australia. Both use large-scale data from multiple global climate models (GCMs). However, the national projections 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.

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

- change in average temperature (°C)
- change in rainfall (%)
- change in the number of days a year FFDI >50
- change in number of days a year max temp > 35 °C
- change in number of cold nights (min temp < 2 °C).

All other projections were adopted from *Climate Change in Australia* (DEH 2018).

The climatic variables identified as potentially generating risk to the Project include – annual average rainfall, extreme rainfall, extreme temperature, extreme wind, and storms (for example, ECLs, hail, lightening), and extreme fire weather. Table 3-1 provides a summary of projections for these climatic variables relevant to the study area.

Table 3-1. Climate projections relevant to the Project study area (OEH 2014)

Climate variable	Units	Current long-term average	Projections	
			2030	2070
Temperature	Daily maximum temperature	-	+0.7 °C (range 0.3 to 1.0 °C)	+1.9 °C (range 1.6 to 2.5 °C)
	Hot days (>35 °C) – Eastern Sydney	5-10 days per year	5-15 days per year	10-25 days per year
	Hot days (>35 °C) – Western Sydney	10-20 days per year	15-30 days per year	20-40 days per year
	Heatwaves – times per year 35 °C exceeded for 3 to 5 consecutive days	1.2 events per year	1.6 (1.3 to 1.9) events per year	4.7 (1.6 to 8.2) events per year
Rainfall	Summer average – percent change	-	Increase 0 to +5 per cent	Increase +10 to +20 per cent
	Autumn average – percent change	-	Increase +5 to +10 per cent	Increase +10 to +20 per cent
	Winter average – percent change	-	Range from decrease by 5 percent to increase by +5 percent	Increase 0 to +10 per cent
	Spring average – percent change	-	Decrease -5 to 0 per cent	Increase 0 to +10 per cent
	Extreme rainfall – percent change 40-year 1 day rainfall total	-	Increase +5 (-3 to +12) per cent	Increase +2 (-7 to +10) per cent

Climate variable	Units	Current long-term average	Projections	
			2030	2070
	Rainfall frequency	Variable	Variable	Variable
ECLs	Frequency	<10 per year	No change	No change
	Intensity	-	Increase	Increase
Fire weather	Severe fire weather	9 days per year	Neutral-Increase, 9 to 11 days per year	Increase, 10 to 15 days per year
Atmospheric CO_2	Amount	-	Increase	Increase

Regardless of the model or projection source (for example, NARCLiM, BoM/CSIRO), they agree that climate projections for the Project study area include:

- average temperatures will continue to increase across all seasons (very high confidence)
- the region will experience more hot days and warm spells (very high confidence)
- the region will experience fewer frosts (high confidence)
- medium rainfall will decrease in the region (medium confidence)
- there will be increased intensity of extreme rainfall events (high confidence)
- mean sea level will continue to rise, and the height of extreme sea-level events will increase (very high confidence)
- there will be a harsher fire-weather climate (high confidence).

Temperature is the most reliable indicator of climate change. Across NSW, including the Sydney region, all model projections show all temperature variables would increase due to climate change, for both the near-future and far-future scenarios (OEH 2014). This increase in temperature will influence other climatic variables, such as storms and extreme rainfall events, extreme heat events (for example, hot days and heatwaves), and extreme fire weather (IPCC 2012).

For the Sydney region, hot days are those above 35°C (OEH 2014). This variable can be influenced by proximity to the coast, therefore projections are provided for both eastern (coastal fringe and areas inland to Hornsby, Parramatta, and Liverpool) and western (from Parramatta and Liverpool west to Mount Victoria, and south including Campbelltown) Sydney regions. Climate change models predict that in the near-future eastern Sydney will experience a small increase of between zero and five more hot days per year compared to the current average. The increase in hot days in western Sydney in the near-future will be greater, with five to ten more expected per year (OEH 2014).

In the far future, the eastern Sydney region is expected to experience 5 to 15 more hot days per year, and the western Sydney region 10 to 20 hot days per year than current averages. The increase in hot days are expected to occur in summer and spring in the near-future, and summer, spring and autumn in the far future (OEH 2014).

Heatwaves are a significant hazard in Australia. They are defined by consecutive stretches of hot days compared to ‘normal’ conditions. With both mean temperatures and the frequency of hot days projected to increase, the occurrence of heatwaves is also projected to occur more often and last longer. Heatwave projection are provided for intensity, frequency and duration (OEH 2014).

Heatwave intensity is projected to increase across NSW in both near- and far-future scenarios. Heatwave frequency is projected to increase by an extra 1 to 1.5 heatwave events per year in the near-future, and by 2.4 to 4.5 events per year in the far-future. Heatwave duration is projected to increase by 1.5 to 3.5 more days in the near-future, and by two to 11 days in the far-future (OEH 2014).

Modelling changes in rainfall patterns is challenging due to the complexities of weather systems that generate rain. Rainfall in the Hawkesbury-Nepean catchment currently exhibits considerable variability from season-to-season and year-to-year. This variability is reflected in climate change projection modelling, and as such, model agreement is used to determine the confidence in the projected change (OEH 2014).

The projections for rainfall recognise natural variability in the climate system over annual and decadal scales, which may mask or enhance any long-term human induced trend, particularly over the coming two decades. Available records do not suggest any long-term trend in rainfall with year-to-year variability strongly influenced by the El Niño-Southern Oscillation (ENSO). As such, natural climate variability was projected to remain the major influence for rainfall changes in the coming decades (DEH 2018). The projections for extreme rainfall are more confident based on a more comprehensive understand of the physical processes that cause extreme rainfall, coupled with model outputs. However, the magnitude of these increases cannot be confidently projected (DEH 2018).

Patterns of the ENSO cycle and other climatic influences may also be affected by climate change. Although large uncertainties exist about the future pattern, El Niño years experienced in NSW are likely to continue to result in lower than average rainfall and become hotter. By comparison, La Niña years are expected to continue to result in higher than average rainfall and become warmer, with storms producing heavy downpours likely to become more frequent, with flooding increasing during these years (OEH 2014).

Extreme rainfall events are often associated with damaging storms and can cause riverine and flash flooding. Rainfall extremes (intensity and duration) are projected to increase in both the near- and far-future (OEH 2014). Statistically significant increases in rainfall intensity have been detected in Australia for short duration rainfall events and are likely to become more evident towards the end of the 21st century (Westra *et al*. 2013).

As discussed earlier, storms and floods in NSW are often associated with ECLs. The patters of historical ECLs are yet to be fully understood, and as such, there is significant uncertainty in model outputs. However, there is consensus that while the frequency of ECLs may remain neutral or show a decline, the frequency of more intense ECLs events will increase.

Average and severe fire weather, or FFDI, is expected to increase in the near- and far-future. Increases are projected mainly in summer and spring. A significant increase in severe fire weather days is projected in the far-future (2070). Projected changes in fire weather conditions suggest that fires will be harder to control.

The existing concentration of atmospheric CO_2 is about 400 parts per million (ppm). The IPCC predicts that under a future with little curbing of emissions, CO_2 concentrations would rapidly rise, reaching 940 ppm by 2100. However, even under emissions reduction scenarios, concentrations would peak at about 540 ppm by 2100 (OEH 2014).

The risks of climate change may not arise directly from changes to climate *per se*, but rather from consequences these may lead to such as impacts to infrastructure, services, and agricultural production. For example, increases in temperature may lead to:

- changes in extreme precipitation (Westra *et al*. 2013) and storm events (for example, ECLs) (Pepler *et al*. 2016)
- wide-ranging impacts on biodiversity, intensifying existing threats (Dunlop *et al*., 2012).

3.3 Flooding impacts in the Hawkesbury-Nepean Valley

The rationale and the process for the selection of the dam raising option is discussed in detail in Chapter 4. Key factors in the selection of the dam raising option included maximising flood mitigation, minimising environmental costs and a higher cost-benefit ratio.

Additional hydrological modelling was undertaken by WMAwater to assess the potential impacts of climate change on flood levels in the Hawkesbury-Nepean Valley (WMAwater, 2019). Their modelling used both NARCliM projections and the Australian Rainfall and Runoff guidelines (GeoScience Australia 2016). The methodology and outcomes of this modelling is discussed in Chapters 4 (Project development and alternatives) and Chapter 15 (Flooding and hydrology) of the EIS.

However, based upon additional climate change and hydrological modelling, to provide a similar flood mitigation benefit, in 2090 the dam may need to be raised by an additional three metres to be resilient to the future impacts of climate change and maintain the downstream benefits. For all raising options considered, the FSL would not change.

Based on the WMAwater modelling to allow for climate change, the original dam raising proposal has been slightly modified. The abutments of Warragamba Dam would be raised by about 17 metres; however, the crest levels of the central spillway would be increased by approximately 12 metres. In the future if predicted climate change impacts occurred, only the spillways (and not the abutments) would require raising to maintain the proposed downstream flood mitigation benefits. The additional raising of the spillways would be subject to further environmental assessment and planning approval at some time in the future.

4 Risk assessment methodology

This climate change risk assessment was carried out in accordance with relevant standards and guidelines, including:

- *Climate Change Impacts and Risk Management – A guide for business and government* (DEH 2006)
- Australian Standard/New Zealand Standard/ISO 31000:2009 Risk Management – Principles and guidelines[3]
- *Draft Technical Guide for Climate Change Adaptation* (Roads and Maritime, unpublished)
- Australian Standard AS 5334-2013 Climate Change Adaptation for Settlements and Infrastructure – A Risk-based Approach
- *Guide to Climate Change Risk Assessment for NSW Local Government* (OEH 2011).

The overall approach as outlined in relevant standards and guidelines is focussed on risk management, and comprises five 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).

In establishing the context, the following were defined or identified:

- climate change projections relevant to the Project area (Section 3)
- the scope of the assessment
- key stakeholders
- the evaluation framework.

4.1 Evaluation framework

The following risk management terminology is used throughout this assessment:

- ***Risk*** – the chance of something happening that will have an impact on objectives of the Project. The risk is measures in terms of likelihood and consequence.
- ***Consequence*** – the outcome or impact of an event expressed qualitatively or quantitatively.
- ***Likelihood*** – a general description of the probability or frequency that an event would occur.

Climate change exposure and risk will vary depending on the nature of engineering, construction, operation or service component. As such, the potential exposure to relevant climate change impacts was identified for key Project components.

Risk scenarios were developed for each of the relationships identified during the initial screening. Each risk scenario was then analysed by assigning a likelihood and consequence rating. The likelihood criteria are shown in Table 4-1, and the consequence criteria are shown in Table 4-2.

[3] The climate change risk identification workshop (Section 4.2) was carried and this report was drafted when this standard was still in force

Table 4-1. Likelihood criteria (AS5334:2013)

Likelihood rating	Description		Probability parameters	
Extreme	Almost certain	The event is expected to occur in most circumstances	>90 per cent	Several times per year
High	Likely	The event will probably occur in most circumstances	51 to 90 per cent	Once in 3 years
Medium	Moderate	The event should occur at some time	21 to 50 per cent	Once in 10 years
Low	Unlikely	The event could occur at some time	10 to 20 per cent	Once in 30 years
Negligible	Rare	The event might occur in exceptional circumstances	<10 per cent	Once in 100 years

Table 4-2. Project consequence criteria (WaterNSW Risk Management Framework)

Consequence	Health and safety	Capability/service delivery	Environment and heritage	Compliance and legal	Financial	Reputation
Negligible	Minor injury or ailment that does NOT require medical treatment or first aid.	Minimal capabilities and or non-critical business processes with negligible performance impact. Activities can be conducted with minor degradation in requirements. Insignificant impact on the ability of WaterNSW to provide services to customers. Some non-critical processes not able to be achieved. Negligible social/economic impacts on a local community	Limited impact contained on-site and fully recoverable with no permanent effect on the environment or heritage.	Minor technical breach but no damages. No monetary penalty but potential increase in administration or operating costs. Indication of interest from Regulator.	Short-term impact on operating funds. Financial loss less than $100,000.	Low profile local media attention with no ongoing impact on the reputation of WaterNSW. Marginal decrease in stakeholder or community support. Occasional complaint. Limited low morale and attitude problems.
Minor	Exposure of public and worker to a hazard that could cause minor injuries or minor adverse health effects. Medical treatment injury.	Limited capabilities and /or business processes is supported for all desired tasks, but there would be some restrictions to the level of performance of non-critical elements. Minor impact on supply or water quality where water supplied for drinking. Minor impact on ability of WaterNSW to provide services to customers. Minor, short-term social/economic impacts on a local community.	Short term localised impacts to the environment. Self-recovery of impacts <2 years with minor intervention. Minor disturbance to heritage value.	Minor technical non-compliances and breaches of regulations or law with potential for minor damages or monetary penalty.	Some short-term impact on operating funds. Revenue or opportunity loss or cost increase of $100,001 to $1,000,000.	High profile detrimental local media attention and minimal impact on the reputation of WaterNSW. Occasional localised complaints. Moderate decrease in stakeholder or community support for a short period. Localised employee morale and attitude problems.
Moderate	Serious health impact on one or more people (workforce or public) attributable to WaterNSW. Public or worker exposed to a hazard that could cause injuries or moderate adverse health effects attributable to WaterNSW. Reportable Lost Time Injury (LTI).	Some capabilities and/or business processes are interrupted and/or conducted in a substandard or limited state. One or more requirements would not be met. Moderate loss of supply (or water quality impact on water supplied for drinking) for a short period. Some social and economic impacts on localised areas.	Localised impacts to the environment that may take up to 5 to 10 years to recover. Moderate disturbance to heritage value requiring some remedial works.	Compliance breach with investigation with prosecution. Legal constraints imposed that affect WaterNSW. Partial achievement of critical legislated/regulatory/licence or governance requirements. Technical legal challenge/ prosecution for minor infringement.	Some difficulty maintaining sufficient operating funds, which requires a rephrasing of Opex (operational expenditure) and Capex (capital expenditure) spend within a 6 to 12 month period. Revenue or opportunity loss or cost increase of $1,000,001 to $10,000,000.	Limited detrimental national or state media attention and moderate impact on the reputation of WaterNSW. Widespread concern on performance raised by stakeholders/community. Impacting on corporate reputation. Widespread customer discontent, community complaints, moderate rectification measures required. Widespread employee morale and attitude problems. Poor reputation as an employer.

Consequence	Health and safety	Capability/service delivery	Environment and heritage	Compliance and legal	Financial	Reputation
Major	Reportable incident or Permanent disability of a person attributable to WaterNSW. Public or worker exposed to a hazard that could result in major surgery or permanent disablement. Serious health impact on multiple members of the public and workforce attributable to WaterNSW.	Some critical capabilities and /or several business processes are interrupted and/ or conducted in a significantly degraded state (exceeding maximum acceptable outage). Significant loss of supply (or water quality impact where water is supplied for drinking) for a short period or moderate loss of supply for an extended period. Significant social and economic impacts on the NSW community.	Widespread impacts on the environment that may take up to 10 to 25 years to recover. Major disturbance to heritage value requiring significant remedial works.	Major compliance breach with potential exposure to large damages or awards. Prosecution results in >50% of maximum penalty imposed.	Significant difficulty maintaining sufficient operating funds to continue operations. Revenue or opportunity loss or Opex or Capex cost increase of >$10,000,001 to $20,000,000.	Major loss of government / regulator / stakeholders / community support. Sustained detrimental national/state media attention with major impact on the reputation of WaterNSW. Serious adverse findings by investigatory bodies. Community outrage. WaterNSW perceived as an unattractive employer.
Severe	Fatality or life-threatening injuries or illness attributable to WaterNSW. Public or worker exposed to a severe, adverse long-term health impact or life-threatening hazard. Widespread public illness attributed to raw water supplied for drinking.	Critical capabilities cease and WaterNSW is unable to conduct core activities, or there is an unacceptable delay in delivery of service. Significant loss of supply (or water quality where water is supplied for drinking) for an unacceptable period. Significant, long-term social and economic impacts on the NSW community.	Widespread environmental and/or heritage impacts which are irreversible.	Multiple or Major Compliance breach/es that together result in prosecution with maximum penalty imposed and/or loss of Operating Licence and/or prosecution of individuals.	Insufficient operating funds to continue operations over a sustained period. Revenue or opportunity loss or Opex and Capex cost increase of >$20,000,001.	Complete loss of government /regulator/shareholder/community support. Detrimental national/state media attention with lasting impact on public confidence / reputation / brand. Subject to parliamentary inquiry. Critical staff loss - unable to be replaced for a substantial time resulting in significant disruption and loss of core capabilities. Severe adverse findings by investigatory bodies

The risk priority matrix used to determine the overall risk level is shown in Table 4-3.

Table 4-3. Risk priority rankings (AS5334:2013)

Likelihood	Consequence				
	Negligible	Minor	Moderate	Major	Severe
Almost certain	Medium	Medium	High	Extreme	Extreme
Likely	Low	Medium	High	High	Extreme
Possible	Low	Low	Medium	High	High
Unlikely	Low	Low	Medium	Medium	High
Rare	Low	Low	Low	Medium	Medium

4.2 Climate change risk identification workshop

An initial assessment of climate change risk for the Project was undertaken with key stakeholders including WaterNSW and Infrastructure NSW. Each relevant (to the Project) climate change variable was assessed to evaluate and identify which of the risks may require treatment. 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.

5 Risk assessment

5.1 Screening

The initial risk screening considered, at a high level, the impact that all climate variables might have on key Project components. This process is 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 climate variables used in the screening were adopted from those used by *Climate Change in Australia* (DEH 2018) and Adapt NSW (OEH 2014) and comprised:

- temperature:
  - mean maximum temperature
  - mean minimum temperature
  - hot days (>35 °C)
  - heatwaves (defined as more than three consecutive hot days compared to 'normal' seasonal averages)
- rainfall:
  - annual and seasonal averages
  - intensity
  - frequency
- extreme weather events:
  - east coast lows
  - storms
  - fire weather
- sea level rise
- wind
- evaporation
- atmospheric CO_2.

The elements of the Project for which these impacts were considered against were determined based on a review of the Project description, and consultation with WaterNSW, and comprised:

- upstream catchment – as defined in Section 1.3
- downstream catchment – as defined in Section 1.3
- 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 5-1 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.

Other elements of the local environment that would potentially be affected by climate change include dam water quality (for example, increased solar radiation leading to increases in stratification), changes in plant community distribution/composition, reduced average water level (for example, due to increased evaporation) and increased bushfires in the catchment. These potential impacts would occur regardless of the Project proceeding - and the complex interaction between these potential climate change impacts and the Project impacts either considered to negligible or impossible to predict. It needs to be recognised that the flood mitigation zone would operate relatively infrequently and for a short duration in comparison to the dam's permanent water supply function – and consequently the potential interactions of Project impacts with other climate change impacts is minimal. Also, if climate changes cause average water levels in the dam to be lower, there would be additional capacity below the FSL to capture flood inflows and the extent and duration of upstream inundation would be reduced.

Table 5-1. 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	-	-	✓	✓	✓	-	-	-	✓	-	-	✓

The main impacts of climate change on the Project relate to projected changes in rainfall patterns, extreme temperature events, and extreme weather events. It is important to note that the key objective of the Project is to provide flood mitigation for downstream communities. The key proposal parameters (for example, raising the dam to create a flood mitigation zone) were considered through extensive modelling of rainfall and flooding by others (WMAwater 2019).

5.1.1 Justification of climate variables excluded

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

- mean maximum temperature
- mean minimum temperature

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

Justifications for why these climate variables were excluded are provided as follows.

5.1.1.1 Mean maximum and minimum temperature

Projected increases in mean maximum and minimum temperatures are in the order of a few degrees over the life of the Project (+100 years). These changes, while significant from a global weather and climate perspective, are unlikely to lead to direct impacts on the aspects of the construction and operation of the Project. However, it is important to note that these changes will exacerbate other climate variables, as discussed in Section 3.2, which have been considered in the risk assessment.

5.1.1.2 Average annual rainfall

Projected changes in rainfall were only considered based on an increase in extreme flood producing rains, or an increase in extended wet periods, as other rain 'parameters' (that is, average annual rainfall) were considered 'business as usual' for the dam construction and operation.

5.1.1.3 Sea-level rise

Sea-level rise impacts for 2100 are projected to occur as far inland as Sackville and the lower Colo River (Coastal Risk Australia 2018). While these impacts would be important to consider when modelling the potential increased flood risk to the Hawkesbury-Nepean valley under climate change scenarios, the risk to the construction and operation of the Project was considered minor to negligible. The interaction of future sea-level rise and rainfall and the effect this may have on the flood risk to the Hawkesbury-Nepean Valley was addressed by WMAwater (2018), and the results are discussed in Chapter 15 (Flooding and hydrology) of the EIS.

5.1.1.4 Mean wind speed

Projections of changed wind patterns under climate change are not specifically presented by NARCliM or the BOM/CSIRO. However, the NSW Department of Environment, Climate Change and Water (2010) state that high winds in the Sydney/Central Coast region are associated with several climatic systems including ECLs, severe thunderstorms, ex-tropical cyclone, and frontal systems. While projections for wind were not specifically addressed in this assessment, projections for ECLs and storms have been.

5.1.1.5 Evaporation

While higher temperatures are likely to result in significant increases in evaporation, this is unlikely to impact upon construction and operation of the Project. Evaporation impacts are associated with drier soil conditions leading to, for example, increased erosion and changes in soil salinity. It was determined that these impacts would not present more than a minor impact to the Project, and therefore were not considered further. However, increases in evaporation rates may impact water stored in Lake Burragorang but these impacts would occur regardless of the Project.

5.1.2 Justification for climate variables included

5.1.2.1 Extreme heat

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.

These are initial risks identified during the screening process. Additional risks may be identified through the detailed risk assessment.

5.1.2.2 Extreme rainfall

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:

- the construction of the Project:
  - extended wet periods may impact upon the staging/timing of the Project
- the operation of the Project:
  - an increase in flood producing rains may reduce the benefit of the flood mitigation zone
  - an increase in flood producing rains may increase the frequency of inundation of the flood mitigation zone, leading to increased environment impacts.

These are initial risks identified during the screening process. Additional risks may be identified through the detailed risk assessment.

5.1.2.3 Extreme weather

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 Section 5.1.2.2. Extreme weather is also associated with high winds, flying debris and lightening, 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.

These are initial risks identified during the screening process. Additional risks may be identified through the detailed risk assessment.

5.1.2.4 Atmospheric CO_2

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

5.2 Detailed risk assessment

Table 5-2 show the risk scenarios that were identified with an unmitigated high or extreme risk rating. The full risk assessment, including risks scenarios rated medium or below is provided in Appendix A.

Table 5-2. High and extreme risks (identified through the risk workshop)

Risk scenario	Likelihood	Justification	Consequence	Justification	Unmitigated risk level
Increase in extreme flood producing rain: Operational - flood mitigation benefit of a flood mitigation zone is lowered.	Almost certain	Rainfall and flood modelling (WMAwater 2019) projected that flood mitigation from an FMZ would be reduced in the long-term under certain climate scenarios.	Major	Reduced benefits of the flood mitigation zone may lead to impacts related to: ▪ health and safety ▪ capability and service delivery ▪ environment and heritage ▪ financial ▪ reputation due to increasing flood risk. (see Table 4-2 for consequence details)	Extreme
Increase in extreme flood producing rain: Operational - upstream increased inundation frequency in the zone immediately above FSL, contributing to potential environmental impacts.	Almost certain	The zone immediately above FSL is almost certain to be more frequently inundated under future extreme rainfall events.	Moderate	Increased upstream inundation frequency may lead to impacts related to ▪ environment due to potential loss of biodiversity, changes in water quality.	High
Increase in consecutive extended wet periods: Construction - flooding impact on works/timing/construction staging.	Likely	Flood and rainfall modelling (WMAwater 2019) indicate that extended wet periods may occur during the construction period The distribution of rainfall is projected to change.	Moderate	Increased extended wet periods causing flooding leading to delays in works/timing/construction staging causing impacts related to: ▪ capability and service delivery ▪ compliance and legal ▪ financial ▪ reputation due to wet weather delays. (see Table 4-2 for consequence details)	High
Increase in consecutive extended wet periods: Construction – flooding or saturation of embankments and ground conditions.	Likely	Flood and rainfall modelling (WMAwater 2019) indicate that extended wet periods may occur during the construction period The distribution of rainfall is projected to change.	Moderate	Increased extended wet periods causing flooding of embankments and ground conditions, leading to impacts related to: ▪ capability and service delivery ▪ environment and heritage ▪ financial due to delayed construction program, and increased erosion. (see Table 4-2 for consequence details)	High
Increase in severe storm events, that is, ECLs: Construction - dam overflow/breach/slip way overflow during construction.	Unlikely	The frequency of ECLs is not projected to increase; however, the intensity of ECLs may increase.	Major	Increase in severe storm events involving flood producing rains may lead to the dam/slipway overflowing/breaching causing impacts related to: ▪ health and safety ▪ capability and service delivery ▪ environment and heritage ▪ financial ▪ compliance and legal ▪ reputation due to extensive downstream flooding, exacerbated due to construction activities. (see Table 4-2 for consequence details)	Medium

Risk scenario	Likelihood	Justification	Consequence	Justification	Unmitigated risk level
Increase in number of hot days/heatwaves: Construction - construction timing/staging impacts.	Almost certain	Number of heatwave events per year within the Project study area projected to increase by 2030.	Moderate	Increase in the number of hot days may lead to delay in construction program, staging leading to impacts related to: ▪ financial ▪ compliance and legal ▪ reputation due to reduced working times enforced due to extreme heat. (see Table 4-2 for consequence details)	High
Increase in number of hot days/heatwaves: Construction - impacts on times of day during which concrete can be poured.	Almost certain	Number of heatwave events per year within the Project study area projected to double by 2030.	Moderate	Increased number of hot days and heatwaves may limit times that concrete can be poured, leading to Impacts related to: ▪ financial ▪ compliance and legal ▪ reputation due to reduction in optimal temperature conditions for concrete pouring. (see Table 4-2 for consequence details)	High

6 Risk treatment recommendations

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, and whether there are any feasible options to reduce predicted impacts. Existing controls and proposed adaptation measures to reduce the likelihood and/or consequences of unmitigated risks were determined during the risk assessment workshop applying the evaluation framework described in Section 4.1 and the criteria and ratings defined in Table 4-1, Table 4-2, and Table 4-3. The results of the risk assessment workshop are summarised in Table 6-1.

Table 6-1. Existing controls, potential adaptation, and residual risk ratings

Risk scenario	Unmitigated Risk level	Existing controls	Treatment/adaptation	Residual risk level
Increase in extreme flood producing rain: ▪ Operational - flood mitigation benefit of raising Warragamba Dam to create an FMZ is lowered.	Extreme	▪ The current Warragamba Dam has no flood mitigation capacity, and the flood risk will increase with climate change. The Project will continue to have flood mitigation benefits compared to the current dam under all projected climate change scenarios	▪ Raising Warragamba Dam to create an FMZ ▪ Raising Warragamba Dam abutments by an additional three metres to be resilient to the future impacts of climate change and maintain the downstream benefits ▪ Other work-streams being implemented under the Hawkesbury-Nepean Flood Strategy.	High
Increase in extreme flood producing rain: ▪ Operational - upstream increased inundation frequency in the zone immediately above the FSL, contributing to potential environmental impacts.	High	▪ Current H14 protocol for controlled discharge of water.	▪ Adaptive catchment management in partnership with relevant stakeholders. ▪ Flood drawdown framework prioritises emptying the FMZ to limit the inundation time/extent.	Medium
Increase in consecutive extended wet periods: ▪ Construction - flooding impact on works/ timing/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: ▪ Construction – 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
Increase in number of hot days/heatwaves: ▪ Construction - Construction	High	▪ Program allowance for stoppages ▪ Contractual inclusions around insurances.	▪ Allowances for work outside of standard hours in approvals and licences.	Medium

Risk scenario	Unmitigated Risk level	Existing controls	Treatment/adaptation	Residual risk level
timing/staging impacts.			▪ Program concrete pours within constraints dictated by temperatures ▪ Cooling concrete aggregates and materials.	
Increase in number of hot days / heatwaves: ▪ Construction - Impacts on times of day during which concrete can be poured.	High	▪ Program allowance for stoppages ▪ Contractual inclusions around insurances ▪ Program concrete pours within constraints dictated by temperatures ▪ Cooling concrete aggregates and materials.	▪ Allowances for work outside of standard hours in approvals and licences.	Medium

The *Climate Change Impacts and Risk Management* guidelines (DEH 2006) provide the following general principles for risk treatment:

- ***Extreme*** risks – these are priority risks that demand urgent attention and cannot be accepted as part of routine operations.
- ***High*** risks – are the most severe risks that can be accepted as part of routine operations.
- ***Medium*** risks – can be expected to form part of routine operations but should be assigned higher management priority.
- ***Low*** risks – can be maintained under review but existing controls should be enough.

6.1 Adaptation measures

A cost-benefit analysis demonstrated that raising Warragamba Dam would provide, on average, a 75 percent reduction in flood damages, reducing the cost of repairs for urban flood damages by billions of dollars. To allow for potential for future rainfall scenarios the design development may also consider infrastructure that would allow the dam to be cost-effectively raised further in the future. For example, based upon additional climate change and hydrological modelling, to provide a similar flood mitigation benefit, in 2090 the dam may need to be raised by an additional three metres to be resilient to the future impacts of climate change. For all raising options considered, the FSL would not change.

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

Climate change mitigation and management measures are presented in Table 6-2. These measures would need to be refined and developed further during subsequent design development and construction planning phases of the Project.

Table 6-2. Climate change mitigation and management measures

Impact	Environmental management measure	Timing	Responsibility
Climate Risk – general	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	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	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	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	Construction sequencing for major works to consider peak ECL season.	Pre-construction	Construction contractor
Climate change – general	Climate change to be considered during health and safety management planning	Pre-construction	Construction contractor

6.2 Conclusions

Importantly, climate change risk assessment and adaptation are intended to be iterative processes. Over the coming years to decades, future emission scenarios may become more refined, and advances in climate (particularly rainfall) modelling may allow for more accurate climate projections (DEH 2018). These should be used to guide both the design development, construction and ongoing operation of the dam.

At the time of preparation of this report, the detailed design for the Project had not been completed. This report should be used to inform the detailed design, as appropriate, with elements incorporated to minimise the impacts associated with climate change.

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Appendix A Preliminary Risk Assessment

	Risk scenario	Project Phase	Consequence detail	Likelihood	Consequence	Risk level	Existing Control	Treatment / Adaptation	Mitigated consequence level	Mitigated risk level
1.1	**Increase in extreme flood producing rainfall**	Construction (2020-2024)	Flooding or saturation of embankments and ground conditions.	Unlikely: - climate projections show little change in flood producing rainfall events (e.g., ECLs) to existing / historic trends	Moderate: - capability and service delivery - compliance and legal - financial - reputation	**Medium**	Allowance for current/historic climate extremes in construction planning.	Assessment of projected extreme rainfall to be considered in flood risk for construction procedures / planning. Upgrading forecasting mechanisms.	Minor: - capability and service delivery - compliance and legal - financial - reputation	**Low**
1.2		Construction (2020-2024)	Flooding impacts works / timing / construction staging.	Unlikely: - climate projections show little change in flood producing rainfall events (e.g., ECLs) to existing / historic trends	Moderate: Financial. - some difficulty maintaining sufficient operating funds, which requires a rephrasing of Opex and Capex spend within a 6 to 12 month period - revenue or opportunity loss or cost increase of $1,000,001 to $10,000,000.	**Medium**	Include: - program allowance for stoppages - contractual inclusions around insurances.	Include: - temporary mechanisms in palce during construction to capture floods - timing of major works outside of ECL sequecning / seasonality.	Minor: Financial. - some short-term impact on operating funds - revenue or opportunity loss or cost increase of $100,001 to $1,000,000.	**Low**
1.3		Construction (2020-2024)	Construction is interrupted / compromised due to operation of the spillways (main and auxillary) during flood, including removal / replacement of gates, fuse plugs etc.	Rare: - climate projections show little change in flood producing rainfall events (e.g., ECLs) to existing / historic trends	Major: - health & safety - environment & heritage - financial	**Medium**	Include: - program allowance for stoppages - contractual inclusions around insurances.	Include: - temporary mechanisms in palce during construction to capture floods - timing of major works outside of ECL sequecning / seasonality.	Moderate: - health & safety - environment & heritage - financial	**Low**
1.4		Construction (2020-2024)	Floods lead to road / bridge closures, restricting transport access routes, plant and equipment supply, workforce movements.	Rare: - climate projections show little change in flood producing rainfall events (e.g., ECLs) to existing / historic trends	Minor: Financial. - some short-term impact on operating funds - revenue or opportunity loss or cost increase of $100,001 to $1,000,000.	**Low**	Flood drawdown framework prioritises maintaining critical infrastructure, road network access etc.	Refine roles, responsibilities, communication protocols with stakeholders - SES, BoM, WaterNSW, RMS, Councils, OEH, Councils.	Minor: Financial. - some short-term impact on operating funds - revenue or opportunity loss or cost increase of $100,001 to $1,000,000.	**Low**
1.5		Operation (design life)	Flood mitigation benefits of the raised (14 m) dam lowered.	Almost certain: - rainfall modelling (WMA) projected that 14 m dam would be compromised in the long-term under certain event scenarios.	Major: - health & safety - capability / service delivery - environment & heritage - financial - reputation	**Extreme**	Include: - constructing a 14 m flood mitigation zone - existing 100 year planning controls do not allow development within 1 in 100.	Include: - ability to adapt to 17 m flood mitigation zone - other workstreams being implemented under the Hawkesbury-Nepean Flood Strategy.	Moderate: - health & safety - capability / service delivery - environment & heritage - financial - reputation	**High**
1.6		Operation (design life)	Degraded water quality / compromised supply due to flooding of catchment - erosion, debris, inundation of vegetated areas.	Almost certain: - large rainfall events would lead to degraded water quality and potential supply issues - WaterNSW has contractual obligations to meet water quality objectives for stakehodlers. .	Minor: Environment and Heritage - short term localised impacts to the environment - self-recovery of impacts <2 years with minor intervention.	**Medium**	Include: - selective withdrawal - catchment management programs (SaSPOM) - water quality monitoring - catchment risk assessments - regular incident scenarios run with stakeholders (NSW Health, Sydney Water, WaterNSW).	Business as usual. Continue adapting strategies.	Minor: Environment. - short term localised impacts to the environment - self-recovery of impacts <2 years with minor intervention.	**Medium**
1.7		Operation (design life)	Upstream - increased inundation frequency in the zone immediately above FSL, contributing to potential environmental impacts.	Almost certain: - the zone immediately above FSL is almost certain to be more frequently inundated under future extreme rainfall events.	Moderate: Environment and Heritage - localised impacts to the environment that may take up to 5 to 10 years to recover.	**High**	Flood drawdown framework prioritises emptying the flood mitigation zone to limit the inundation time / extent.	Adaptive catchment management in partnership with NP (SaSPOM).	Minor: Environment. - short term localised impacts to the environment - self-recovery of impacts <2 years with minor intervention.	**Medium**
1.8		Operation (design life)	Downstream - extended duration of release, contributing to incremental increases in bridge / road closures for some events.	Almost certain: - extended wet periods leading to extended periods of release are almost certain to occur in the far-future.	Minor: - health & safety - environment & heritage - reputation	**Medium**	Flood drawdown framework prioritises maintaining critical infrastructure, road network access etc.	Refine roles, responsibilities, communication protocols with stakeholders - SES, BoM, WaterNSW, RMS, Councils, OEH, Councils.	Minor: - health & safety - environment & heritage - reputation	**Medium**
2.1	**Increase in consecutive extended wet periods**	Construction (2020-2024)	Construction is interrupted / compromised due to operation of the spillways (main and auxillary) during flood, including removal / replacement of gates, fuse plugs etc.	Possible: - flood and rainfall modelling (WMA Water, 2017) indicate that extended wet periods may occur during the construction period - the distribution of rainfall is projected to change	Moderate: - health & safety - environment & heritage - financial	**Medium**	Include: - program allowance for stoppages - contractual inclusions around insurances.	Include: - temporary mechanisms in place during construction to capture floods - timing of major works outside of ECL sequencing / seasonality.	Moderate: - health & safety - environment & heritage - financial	**Medium**
2.2		Construction (2020-2024)	Flooding impact on works / timing / construction staging	Likely: - flood and rainfall modelling (WMA Water, 2017) indicate that extended wet periods may occur during the construction period - the distribution of rainfall is projected to change	Moderate: - capability and service delivery - compliance and legal - financial - reputation	**High**	Include: - program allowance for stoppages - contractual inclusions around insurances.	Include: - temporary mechanisms in place during construction to capture floods - timing of major works outside of ECL sequecning / seasonality.	Minor: • capability and service delivery • compliance and legal • financial • reputation	**Medium**
2.3		Construction (2020-2024)	Flooding or saturation of embankments and ground conditions	Likely: - flood and rainfall modelling (WMA Water, 2017) indicate that extended wet periods may occur during the construction period - the distribution of rainfall is projected to change	Moderate: - capability and service delivery - environment and heritage - financial	**High**	Include: - program allowance for stoppages - contractual inclusions around insurances - erosion and sediment control.	Include: - temporary mechanisms in place during construction to capture floods - timing of major works outside of ECL sequecning / seasonality - on-site environmental management.	Minor: • capability and service delivery • environment and heritage • financial	**Medium**
2.4		Construction (2020-2024)	Restriction on supply / transport access routes, workforce movements.	Likely: - flood and rainfall modelling (WMA Water, 2017) indicate that extended wet periods may occur during the construction period - the distribution of rainfall is projected to change	Minor: Financial. - some short-term impact on operating funds - revenue or opportunity loss or cost increase of $100,001 to $1,000,000.	**Medium**	Include: - program allowance for stoppages - contractual inclusions around insurances.	Include: - temporary mechanisms in place during construction to capture floods - timing of major works outside of ECL sequecning / seasonality.	Minor: Financial. - some short-term impact on operating funds - revenue or opportunity loss or cost increase of $100,001 to $1,000,000.	**Medium**
2.5		Operation (design life)	Flood mitigation benefits of the raised (14 m) dam lowered.	Rare: - modelling (WMA Water, 2017) projects that extended wet periods would not compromise the benefits of a raised dam	Minor: - health and safety - capability / service delivery - environment and heritage - compliance and legal - financial - reputation	**Low**	Include: - constructing a 14 m flood mitigation zone - existing 100 year planning controls do not allow development within 1 in 100.	Include: - ability to adapt to 17 m flood mitigation zone - other workstreams being implemented under the Hawkesbury-Nepean Flood Strategy.	Minor: - health and safety - capability / service delivery - environment and heritage - compliance and legal - financial - reputation	**Low**
2.6		Operation (design life)	Degraded water qualitty / compromised supply due to flooding of catchment - erosion, debris, inundation of vegetated areas.	Unlikely: - incremental increase considered unlikely to alter current operating parameters	Minor: Environment and Heritage - short term localised impacts to the environment - self-recovery of impacts <2 years with minor intervention.	**Low**	Include: - selective withdrawal - catchment management programs (SaSPOM) - water quality monitoring - catchment risk assessments - regular incident scenarios run with stakeholders (NSW Health, Sydney Water, WaterNSW).	Business as usual. Continue adapting strategies.	Minor: Environmental - short term localised impacts to the environment - self-recovery of impacts <2 years with minor intervention.	**Low**
2.7		Operation (design life)	Upstream - increased inundation duration and frequency in the zone immediately above FSL, contributing to potential environmental impacts.	Likely: - flood and rainfall modelling (WMA Water, 2017) indicate that extended wet periods may occur during the construction period - the distribution of rainfall is projected to change	Minor: Environment and Heritage - short term localised impacts to the environment - self-recovery of impacts <2 years with minor intervention.	**Medium**	Flood drawdown framework prioritises emptying the flood mitigation zone to limit the inundation time / extent.	Adaptive catchment management in partnership with NP (SaSPOM).	Minor: Environment. - short term localised impacts to the environment - self-recovery of impacts <2 years with minor intervention.	**Medium**
2.8		Operation (design life)	Downstream - extended duration of release, contributing to incremental increases in bridge / road closures for some events.	Likely: - flood and rainfall modelling (WMA Water, 2017) indicate that extended wet periods may occur during the construction period - the distribution of rainfall is projected to change	Minor: - health & safety - environment & heritage - reputation	**Medium**	Flood drawdown framework prioritises maintaining critical infrastructure, road network access etc.	Refine roles, responsibilities, communication protocols with stakeholders - SES, BoM, WaterNSW, RMS, Councils, OEH, Councils.	Minor: - health & safety - environment & heritage - reputation	**Medium**
3.1	**Increase in number of wet days**	Construction (2020-2024)	Days lost to wet weather days	Almost certain: - numberof wet days may change in the future under certain scenarios	Negligible: - capability and service delivery - financial	**Medium**	Include: - program allowance for stoppages - contractual inclusions around insurances - procedures for shutdown of critical infrastructure to minimise risk.		Negligible: - capability and service delivery - financial	**Medium**

4.1	**Increase in severe storm events, i.e., ECLs**	Construction (2020-2026)	Dam overflow / breach / slip way overflow during construction.	Unlikely: - the frequency of ECLs is not projected to increase; however, the intensity of ECLs may increase	Major: - health and safety - capability and service delivery - environment and heritage - financial - legal and compliance - reputation.	**Medium**	Include: - program allowance for stoppages - contractual inclusions around insurances - procedures for shutdown of critical infrastructure to minimise risk.	Include: - temporary mechanisms in place during construction to capture floods - timing of major works outside of ECL sequecning / seasonality.	Moderate: - health and safety - capability and service delivery - environment and heritage - financial - legal and compliance - reputation.	**Medium**
4.2		Construction (2020-2024)	Construction timing / staging / sequencing	Unlikely: - the frequency of ECLs is not projected to increase; however, the intensity of ECLs may increase	Moderate: Financial. - some difficulty maintaining sufficient operating funds, which requires a rephrasing of Opex and Capex spend within a 6 to 12 month period - revenue or opportunity loss or cost increase of $1,000,001 to $10,000,000.	**Medium**	Include: - program allowance for stoppages - contractual inclusions around insurances - procedures for shutdown of critical infrastructure to minimise risk.	Include: - temporary mechanisms in place during construction to capture floods - timing of major works outside of ECL sequecning / seasonality.	Minor: Financial. - some short-term impact on operating funds - revenue or opportunity loss or cost increase of $100,001 to $1,000,000.	**Low**
5.1	**Increase in number of hot days.**	Construction (2020-2026)	Health and safety risk to construction workforce.	Almost certain: - number of hot days per year within the proposal area projected to increase by 5 to 10 in the near future	Minor: Health and Safety. - exposure of public and worker to a hazard that could cause minor injuries or minor adverse health effects - medical treatment injury.	**Medium**	Existing legislation and controls.	Existing legislation and controls.	Minor: Health and Safety. - exposure of public and worker to a hazard that could cause minor injuries or minor adverse health effects - medical treatment injury.	**Medium**
5.2		Construction (2020-2024)	Construction timing / staging impacts	Almost certain: - number of hot days per year within the proposal area projected to increase by 5 to 10 in the near future	Moderate: - financial - compliance and legal - reputation	**High**	Include: • program allowance for stoppages • contractual inclusions around insurances • program concrete pours within constraints dictated by temperatures • cooling concrete aggregates and materials.	Include: • allowances for night work in approvals and licenses.	Minor: - financial - compliance and legal - reputation	**Medium**
5.3		Construction (2020-2024)	Impacts on times of day during which concrete can be poured.	Almost certain: - number of hot days per year within the proposal area projected to increase by 5 to 10 in the near future	Moderate: - financial - compliance and legal - reputation	**HIgh**	Include: • program allowance for stoppages • contractual inclusions around insurances • program concrete pours within constraints dictated by temperatures • cooling concrete aggregates and materials.	Include: • allowances for night work in approvals and licenses.	Minor: - financial - compliance and legal - reputation	**Medium**
6.1	**Increase in heatwave days.**	Construction (2020-2026)	Health and safety risk to construction workforce.	Almost certain: - number of heatwave events per year within the proposal area projected to double in the near future	Minor: Health and Safety. - exposure of public and worker to a hazard that could cause minor injuries or minor adverse health effects - medical treatment injury.	**Medium**	Existing legislation and controls.	Existing legislation and controls.	Minor: Health and Safety. - exposure of public and worker to a hazard that could cause minor injuries or minor adverse health effects - medical treatment injury.	**Medium**
6.2		Construction (2020-2024)	Construction timing / staging impacts	Almost certain: - number of heatwave events per year within the proposal area projected to double in the near future	Moderate: - financial - compliance and legal - reputation	**High**	Include: • program allowance for stoppages • contractual inclusions around insurances • program concrete pours within constraints dictated by temperatures • cooling concrete aggregates and materials.	Include: • allowances for night work in approvals and licenses.	Minor: - financial - compliance and legal - reputation	**Medium**
6.3		Construction (2020-2024)	Impacts on times of day during which concrete can be poured.	Almost certain: - number of heatwave events per year within the proposal area projected to double in the near future	Moderate: - financial - compliance and legal - reputation	**High**	Include: • program allowance for stoppages • contractual inclusions around insurances • program concrete pours within constraints dictated by temperatures • cooling concrete aggregates and materials.	Include: • allowances for night work in approvals and licenses.	Minor: - financial - compliance and legal - reputation	**Medium**
7.1	**Fire weather days**	Operation (design life)	Increase in fire weather days leading to bushfires in the catchment, leading to impacts to water quality	Possible: - fire weather days projected to increase in the near and far future	Moderate: Environment & Heritage. - localised impacts to the environment that may take up to 5 to 10 years to recover - moderate disturbance to heritage value requiring some remedial works.	**Medium**	Existing controls?		Moderate: Environment & Heritage. - localised impacts to the environment that may take up to 5 to 10 years to recover - moderate disturbance to heritage value requiring some remedial works.	**Medium**
8.1	**Increased atmospheric CO2**	Operation (design life)	Increased atmospheric CO2 may lead to increased rainfall acidity.	Unlikely: - increase in atmospheric CO2 unlikely to increase acidity of rainfall to a significant extent based on current science	Minor: - capability and service delivery - environment and heritage - financial	**Low**	N/A	N/A	N/A	**Low**

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