24 Climate change risk and adaptation

The NSW Government has acknowledged that, despite efforts to reduce greenhouse gas emissions, some climate change is now inevitable. Adapting to these changes is necessary to minimise the impacts of climate change on natural and built environments, on communities and the economy, and aligns with the Australian Government's *National Climate Resilience and Adaptation Strategy* (2015) and the NSW Government's *Climate Change Policy Framework* (NSW Office of Environment and Heritage 2016).

For the M4-M5 Link project (the project), NSW Roads and Maritime Services (Roads and Maritime) has determined that an assessment of the potential impacts of climate change on the project is warranted, given the significant investment required for the project, the long design life of the project, and its exposure to potential flooding impacts. This chapter outlines the methodology adopted to assess the impacts of climate change on the project and adaptation measures that have been incorporated in the design of the project, as well as recommendations for further development of adaptation options during the project's detailed design. Impacts of the project on climate change relate to greenhouse gas emissions generated from the construction and operation of the project. Greenhouse gas emissions have been assessed in **Chapter 22** (Greenhouse gas).

The Secretary of the NSW Department of Planning and Environment (DP&E) has issued environmental assessment requirements for the project. These are referred to as the Secretary's Environmental Assessment Requirements (SEARs). **Table 24-1** sets out these requirements and the associated desired performance outcomes as they relate to climate change risk, and identifies where they have been addressed in this environmental impact statement (EIS).

Table 24-1 SEARs – climate change risk

Desired performance outcome	SEARs	Where addressed in the EIS
17. 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.	This chapter, and **Appendix X** (Climate change risk assessment framework), present a climate change risk assessment for the project in accordance with current guidelines as listed in **section 24.1**.
	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.	Climate change risks to the project are identified in **section 24.3**, **section 24.4** and **Appendix X** (Climate change risk assessment framework), with reference to current climate change projections presented in **section 24.2.2**.
12. Flooding The project minimises adverse impacts on existing flooding characteristics. Construction and operation of the project avoids or minimises the risk of, and adverse impacts from, infrastructure flooding, flooding hazards, or dam failure.	1. The Proponent must assess (and model where required) the impacts on flood behaviour during construction and operation for a full range of flood events up to the probable maximum flood (PMF) (taking into account sea level rise and storm intensity due to climate change).	Flooding is addressed in **Chapter 17** (Flooding and drainage) and **Appendix Q** (Technical working paper: Surface water and flooding). Changes to rainfall frequency and/or intensity as a result of climate change are also discussed in **Appendix X** (Climate change risk assessment framework) and **section 24.2**.

During detailed design, a detailed climate change risk assessment would be undertaken (in accordance with the standard AS 5334-2013 Climate change adaptation for settlements and infrastructure - A risk based approach), informed by the initial climate change risk assessment set out in this chapter.

24.1 Assessment methodology

Roads and Maritime is currently in the process of finalising a *Technical Guide for Climate Change Adaptation for the State Road Network* (Roads and Maritime (unpublished) 2015) (Technical Guide). The Technical Guide would be aligned with existing Roads and Maritime processes, such as risk management and environmental planning, as well as broader NSW Government initiatives and programs responding to climate change impacts. Although the Technical Guide is not yet published, this assessment adopts the approach of the latest draft to ensure consistency with Roads and Maritime's planned approach to climate change adaptation.

The assessment set out in this chapter considers the impact of future climate change on the project, rather than the impacts of the project on the future of climate change, which relate to greenhouse gas emissions generated from the construction and operation of the project. Greenhouse gas emissions have been assessed in **Chapter 22** (Greenhouse gas).

In addition to the Technical Guide, the climate change risk assessment has been conducted in line with the following relevant standards and current guidelines:

- The risk assessment approach set out in AS/NZS ISO 31000:2009 Risk Management – Principles and Guidelines and ISO/IEC 31010 Risk Management – Risk assessment techniques
- AS 5334-2013 Climate change adaptation for settlements and infrastructure – A risk based approach, which follows ISO 31000:2009 Risk Management – Principles and guidelines
- *Australian Government, Climate Change Impacts & Risk Management – A Guide for Business and Government*, Australian Government (2006)
- *Guideline for Climate Change Adaptation*, Revision 2.1, Australian Green Infrastructure Council (2011)
- *Guidelines for Risk Management* (Roads and Maritime 2014).

The overall approach is focused on risk management and is closely aligned with AS/NZS 31000:2009 Risk Management and complements Roads and Maritime's *Guidelines for Risk Management*. The approach is detailed in the draft *Technical Guide: Climate Change Adaptation for the Road Network* (Roads and Maritime (unpublished) 2015), and comprises the following steps:

- Pre-screening
- Screening
- Detailed risk assessment
- Risk evaluation
- Adaptation (risk treatment).

Each of these steps is described in the following sections.

24.1.1 Pre-screening

A pre-screening exercise was undertaken by Sydney Motorway Corporation (SMC) and Roads and Maritime prior to this assessment to determine whether the project is likely to be impacted by climate change. As part of the exercise, key issues were considered to determine whether the project warrants consideration of climate change. These key issues included:

- Site location and project objectives
- Climate variables of relevance to the project
- Existing climate exposure of the local surroundings
- Likely capacity of project components to withstand changes in climate

- Significance of the project infrastructure and willingness to accept risk
- Desired level or service
- Design life.

It was determined that an assessment of the impact of climate change on the project is warranted due to the significant investment required, the long design life of the project, and its exposure to potential flooding impacts (in particular at Rozelle).

24.1.2 Screening

Screening aims to identify potential exposure to relevant climate change impacts. Each road infrastructure project has a range of engineering components and service provisions and is subject to different climate change impacts and risks. It is therefore not appropriate to consider a generic list of climate change risks.

For the project, specific risks were identified using a screening matrix, which plots relevant elements of the project on one axis and key climate change variables relevant to the region on the other axis. By identifying the intersection between the climate change variables and the elements of the project, relationships can be identified and used to form the basis of potential risk scenarios for further analysis. This step forms part of the 'risk identification' stage of a typical risk management process as described in Roads and Maritime's *Guidelines for Risk Management*.

A multidisciplinary workshop was held on 8 September 2016 with key members of the project design team to identify and validate the project's exposure to climate change and inform the development of risk scenarios specific to the project, as discussed in **section 24.1.3**. The climate change risk screening for the project is provided in **Appendix X** (Climate change risk assessment framework).

24.1.3 Detailed risk assessment

The first step of the detailed risk assessment was the formulation of risk scenarios for each of the relationships identified in the screening stage. Each risk scenario was then analysed in detail by assigning a likelihood and consequence rating. The criteria used for likelihood and consequence (following the Roads and Maritime *Guidelines for Risk Management*) are shown in Table 1-1 and Table 1-2 of **Appendix X** (Climate change risk assessment framework). The consequence rating considers the potential consequences for the physical asset (damages), service provision (loss), safety, the environment and the community.

By combining the likelihood and consequence rating for each risk scenario, using the risk ranking matrix in **Table 24-2**, a level of risk can be determined. These levels represent that risk that exists before any mitigation or adaptation treatments are applied. For example, a risk with medium likelihood and low consequence results in a risk level of low.

The detailed risk assessment for the project is provided in **Appendix X** (Climate change risk assessment framework).

Table 24-2 Risk level matrix

	Consequence					
		Negligible	**Low**	**Medium**	**High**	**Extreme**
Likelihood	**Extreme**	Medium	High	Extreme	Extreme	Extreme
	High	Low	Medium	High	Extreme	Extreme
	Medium	Negligible	Low	Medium	High	Extreme
	Low	Negligible	Negligible	Low	Medium	High
	Negligible	Negligible	Negligible	Negligible	Low	Medium

24.1.4 Risk evaluation

The purpose of risk evaluation was to identify which risks require treatment, through either mitigation or adaptation. Treatments should be applied to those risks evaluated as extreme or high. Risks evaluated as negligible or low do not require any further consideration.

As this is a preliminary climate change risk assessment, and a subsequent detailed risk assessment would be undertaken during detailed design, any risks rated medium or higher have been retained for further consideration. The risk evaluation for the project is provided in **section 24.3.1** and **section 24.4.1**.

24.1.5 Adaptation (risk treatment)

This step involves the development of risk treatments that can reduce the original unmitigated risk rating. Adaptation measures incorporated in the project design at this stage are associated with broader design refinements and opportunities for optimisation, as discussed in **section 24.5.1**. Additional options for further consideration during the detailed design of the project are provided in **section 24.5.2**.

24.2 Existing environment

An increase in global concentrations of greenhouse gases has led to an increase in the Earth's average temperature (surface temperature) (Intergovernmental Panel on Climate Change (IPCC) 2013)). The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2013) states that 'human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system'.

In 2015, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Bureau of Meteorology (BoM) released an assessment of observed climate change and projected future changes in Australia over the 21st century (CSIRO and BoM 2015a). This recent assessment confirms the long-term warming trend, showing that in Australia, the average surface air temperature has increased by 0.9°C since records began in 1910, with most of the warming occurring since 1950. Australia's warmest year since 1910 was 2013 (CSIRO and BoM 2015a).

The AR5 states with high confidence that Australia is already experiencing impacts from climate change. Observed trends include changes in the frequency of air temperature extremes, changes in mean and extreme rainfall, changes in the frequency and intensity of storm events, ocean warming, ocean acidification and sea level rise.

Due to the long lag times associated with climate processes, even if greenhouse gas emissions are mitigated and significantly reduced, the warming trend and associated impacts of climate change are expected to continue for centuries (IPCC 2013). Key projected trends include:

- Increase in atmospheric carbon dioxide concentrations
- Increase in mean temperature
- Increase in frequency, intensity and duration of heat extremes
- Decrease in frequency, intensity and duration of cold extremes
- Changes in mean rainfall
- Changes in the intensity and frequency of extreme rainfall and storm events
- Rise in sea level
- Increase in extreme sea levels (eg storm surge)
- Increase in ocean acidity
- Increase in bushfire weather.

The magnitude of these projected changes would vary both spatially and temporally (IPCC 2013).

Appendix X (Climate change risk assessment framework) provides information on the existing climate and historical climate trends of the project footprint.

24.2.1 Policy setting

In 2015, the Australian Government released the *National Climate Resilience and Adaptation Strategy*, which recognises Australia's vulnerability to climate change and provides a set of principles to guide effective adaptation and build the resilience of Australia's communities, economy and environment. The guiding principles include priorities for:

- Shared responsibility and collaboration among stakeholders
- Climate risk factored into decision making
- A risk management approach based on the best available scientific data
- Assisting the vulnerable
- The importance of monitoring decisions and outcomes over time.

The Strategy identifies the need to consider future climate and extreme weather events in the design and construction of infrastructure, and references the Australian Government's *Critical Infrastructure Resilience Strategy: Policy Statement* (2015), which aims for the continued operation of critical infrastructure and essential services in the face of all hazards.

In 2016, the NSW Government released a new *Climate Change Policy Framework*, which aims to maximise the economic, social and environmental wellbeing of NSW in the context of a changing climate. The Framework includes the development and implementation of a *Draft Climate Change Fund Strategic Plan 2017–2022* and *A Draft Plan to Save NSW Energy and Money*.

The *Draft Climate Change Fund Strategic Plan 2017–2022* sets out priority investment areas for funding over the next five years, including up to $100 million in new funding for actions to prepare NSW for a changing climate. As part of this priority investment area, the *Draft Climate Change Fund Strategic Plan 2017–2022* identifies actions for reducing the costs to public and private assets arising from climate change, reducing the impacts of climate change on health and wellbeing, particularly for vulnerable communities, and managing the impacts of climate change on natural resources, natural ecosystems and communities.

Further discussion of the policy setting for climate change mitigation and emissions reduction is provided in **Chapter 22** (Greenhouse gas) and summarised in **Chapter 27** (Sustainability).

24.2.2 Future climate

This section discusses the selection of climate projections relevant to the project and provides a summary of projections for key climate change variables.

Selection of climate change projections

Climate change projections selected to inform this risk assessment are based on information published by CSIRO and BoM in 2015. The design life of the project is 100 years. As such, projections modelled for 2030 (an average of the period 2020–2039) and 2090 (an average of the period 2080–2100) have been selected for the assessment. These are the available projections for the time horizon closest to project opening and the end of the project design life, respectively.

Projections for southeast Australia have also been published by the NSW and the Australian Capital Territory (ACT) Regional Climate Modelling (NARCliM) project (2014) in collaboration with OEH. These projections are based on the earlier climate models used for the IPCC's Fourth Assessment Report (AR4) and provide downscaled climate change data for a 10 kilometre resolution specific to NSW and the ACT.

While both sets of projections provide robust information on possible changes to the NSW climate, NARCliM projections are not yet available for a number of key climate variables (extreme rainfall, sea level rise, storm surge, wind speed) and the 'far future' projections are limited to projections from 2060 to 2079. This presents limitations when considering climate change impacts on road planning.

For the purposes of this climate change risk assessment, it is considered prudent to consider the potential impact of sea level rise on the project, given the project's proximity to the coastline, particularly at Rozelle Bay, and the sensitivity of road infrastructure to inundation impacts. Therefore, projections provided by CSIRO and BoM are considered most appropriate for this project and are recommended in the draft *Technical Guide: Climate Change Adaptation for the Road Network* (Roads and Maritime (unpublished) 2015).

It is important that a single source of projections is used as this ensures an 'internally consistent climate future' is presented, with a consistent set of assumptions, scenarios and modelling methods applied to each projection to represent the complex interactions that occur between climate variables within the climate system. As such, only the CSIRO and BoM projections have been used. Regardless, the purpose of this chapter is to inform a climate change risk assessment and the difference between the sources of projections is not considered to impact on the development of risk scenarios for the project, except where data is unavailable for particular climate variables, such as sea level rise.

Summary of climate change projections

Projections are presented for two emission scenarios or possible pathways, referred to as 'representative concentration pathways' (RCPs), each reflecting a different concentration of global greenhouse gas emissions. The two RCPs reported here are Intermediate emissions (RCP4.5) and High emissions (RCP8.5). Intermediate emissions projections are only provided in this report for context. The assessment is based on 'High' emissions projections, to account for a worst case scenario based on the precautionary principle.

The projections published by CSIRO and BoM (2015b) are spatially divided into eight natural resource management 'clusters', which largely correspond to broad-scale climate and biophysical regions of Australia. The project falls within the East Coast cluster. Due to the large north- south extent of the East Coast cluster and the diversity of the region, climate change projections are presented for the East Coast South sub-cluster where available. The sub-cluster extends from the south of Sydney to the Queensland border. Projections at this scale are considered appropriate for the consideration of future climate for road projects, in line with guidance provided in the draft *Technical Guide: Climate Change Adaptation for the Road Network* (Roads and Maritime, unpublished 2015).

A summary of projections for the East Coast cluster for 2030 and 2090, for both the Intermediate and High emissions scenarios, is provided in **Table 24-3**. Projections are provided for the East Coast South sub-cluster or Sydney where data at that resolution is available. This table is followed by a description of each climate variable.

Table 24-3 Projections for the East Coast Cluster for 2030 and 2090

Climate variable	2030		2090	
	Intermediate emissions	High emissions	Intermediate emissions	High emissions
Mean surface temperature (East Coast South projections)	Increase of 0.6°C to 1.0°C	Increase of 0.7°C to 1.3°C	Increase of 1.3°C to 2.5°C	Increase of 2.9°C to 4.6°C
Extreme temperature (days per year) (Projections for Sydney)	4.3 days over 35°C 0.5 days over 40°C	Data not available (projections expected to be similar to intermediate emissions for 2030)	6.0 days over 35°C 0.9 days over 40°C	11 days over 35°C 2.0 days over 40°C
Mean annual rainfall (%) (East Coast South projections)	Between a decrease of 10% and increase of 6%	Between a decrease of 11% and increase of 6%	Between a decrease of 16% and increase of 9%	Between a decrease of 20% and increase of 16%
Extreme Rainfall (one in 20 year, %) (East Coast South projections)	Data not available	Data not available	Increase by 0% to 30%	Increase by 5% to 40%
Mean annual wind speed (%) (East Coast South projections)	Between a decrease of 2.9% and increase of 0.5%	Between a decrease of 2.3% and increase of 1.9%	Between a decrease of 4.2% and increase of 0.2%	Between a decrease of 6.9% and increase of 4.2%
Bushfire weather (annual cumulative Forest Fire Danger Index (FFDI)/number of days with a fire danger rating of severe and above) (East Coast projections)	Increase of annual cumulative FFDI by 5% Increase of number of days with a fire danger rating of severe and above by 20%	Increase of annual cumulative FFDI by 12% Increase of number of days with a fire danger rating of severe and above by 45%	Increase of annual cumulative FFDI by 13% Increase of number of days with a fire danger rating of severe and above by 45%	Increase of annual cumulative FFDI by 30% Increase of number of days with a fire danger rating of severe and above by 130%
Sea level (m) (compared to 1986–2005) (Projections for Sydney)	Increase of 0.09 m to 0.18 m	Increase of 0.10 m to 0.19 m	Increase of 0.30 m to 0.65 m	Increase of 0.45 m to 0.88 m

Source: CSIRO and BoM 2015b

Mean surface temperature

Mean surface temperature is projected to continue warming during the 21st century, at a rate that strongly reflects the increase in global greenhouse gas emissions (CSIRO and BoM 2015b). Mean surface temperatures are projected to increase by 0.6°C to 1.1°C by 2030, and 1.3°C to 2.5°C by 2090, under an 'Intermediate' emissions scenario.

Under a 'High' emissions scenario, mean surface temperatures are projected to increase by 0.7°C to 1.3°C by 2030 and by 2.9°C to 4.6°C by 2090. There is very high confidence in these projections (CSIRO and BoM 2015b).

Extreme temperature

The trend of increasing extreme temperatures is projected to continue, with increases in the annual number of days over 35°C and 40°C projected for Sydney. The current annual number of days over 35°C in Sydney is 3.1, and the current annual number of days over 40°C in Sydney is 0.3.

Under an 'Intermediate' emissions scenario, the annual number of days over 35°C is projected to increase for Sydney by 1.2 days by 2030 (to 4.3 days in total) and 2.9 days by 2090 (to 6.0 days in total). The annual number of days over 40°C is projected to increase by 0.2 days by 2030 (to 0.5 days in total) and 0.6 days by 2090 (to 0.9 days in total) (CSIRO and BoM 2015b).

Under a 'High' emissions scenario, the annual number of days over 35°C and 40°C is projected to increase by 7.9 (to 11 in total) and 1.7 (to two in total) days respectively by 2090 (CSIRO and BoM 2015b). There is very high confidence in these projections (CSIRO and BoM 2015b).

Mean annual rainfall

Projections for mean annual rainfall are influenced by changes in seasonal variability. Projections for seasonal rainfall indicate a reduction in winter rainfall, based on medium confidence and good understanding of the natural climate drivers, including a projected southward shift of winter storm systems (CSIRO and BoM 2015b). Climate models project a range of changes in rainfall for other seasons, with less certainty around the driving climate processes for these periods.

As a result of the variability in model results, CSIRO and BoM recommend considering future climate scenarios that are both drier and wetter (2015b). However, it is projected that extreme rainfall events would become more frequent and intense (refer to discussion of extreme rainfall below).

There is low confidence in mean rainfall projections (CSIRO and BoM 2015b). There is generally a high degree of uncertainty in rainfall projections because mean rainfall in Australia is influenced by a number of climate drivers, and there is no consensus on how these drivers would be affected by and respond to climate change.

Extreme rainfall

Projections of extreme rainfall events (wettest day of the year and wettest day in 20 years) are projected to increase in intensity across Australia. By 2090, one in 20 year events are expected to increase by between zero and 30 per cent under an 'Intermediate' emissions scenario and between five and 40 per cent under a 'High' emissions scenario (CSIRO and BoM 2015b).

There is high confidence that the intensity of extreme rainfall would increase in the East Coast cluster; however, the magnitude of the change cannot be reliably projected (CSIRO and BoM 2015b).

The flood modelling undertaken for the project, summarised in **Chapter 17** (Flooding and drainage) and **Appendix Q** (Technical working paper: Surface water and flooding), considers the impact of climate change on rainfall using the approach recommended in the *Practical Considerations of Climate Change – Floodplain Risk Management Guideline* (NSW Department of Environment and Climate Change 2007). Use of the *Practical Considerations of Climate Change – Floodplain Risk Management Guideline* is in accordance with the draft *Technical Guide: Climate Change Adaptation for the Road Network* (Roads and Maritime (unpublished) 2015).

The *Practical Considerations of Climate Change – Floodplain Risk Management Guideline* recommends that sensitivity analyses should be undertaken based on increased rainfall intensities of between 10 and 30 per cent. Under present day climatic conditions, increasing the 100 year ARI design rainfall intensities by 10 per cent would produce about a 200 year ARI flood. Increasing the 100 year ARI design rainfall intensities by 30 per cent would produce about a 500 year ARI flood.

Geoscience Australia recently released the updated *Australian Rainfall and Runoff: A guide to flood estimation* (2016) (ARR), which includes updated guidance for consideration of climate change in design rainfall intensity frequency duration and design flood events. The updated ARR approach is based on the latest climate change science, in accordance with the IPCC Fifth Assessment Report, and uses projections from CSIRO and BoM (as per **Table 24-3**). Flood modelling for the project was already underway when the updated guidance was released. Use of the updated ARR approach would be considered as part of the project's detailed design. **Chapter 17** (Flooding and drainage) and **Appendix Q** (Technical working paper: Surface water and flooding) provide further information regarding the updated ARR approach.

Mean annual wind speed

Under both an 'Intermediate' emissions scenario and a 'High' emissions scenario, there is little change projected in mean wind speed by 2030 and 2090 (CSIRO and BoM 2015b). There is low to medium confidence in these projections (CSIRO and BoM 2015b).

Bushfire weather

Projections of weather conducive to bushfires show that projected warming and drying would lead to fuels that are drier, with increases in the average FFDI and a greater number of days with a severe fire danger rating and above (CSIRO and BOM 2015b).

Under an 'Intermediate' emissions scenario, cumulative FFDI is projected to increase by five per cent by 2030 and 13 per cent by 2090, and the number of days with severe fire danger is projected to increase by 20 per cent by 2030 and 45 per cent by 2090. Under a 'High' emissions scenario, cumulative FFDI is projected to increase by 12 per cent by 2030 and 30 per cent by 2090 and the number of days with a fire danger rating of severe and above is projected to increase by 45 per cent by 2030 and 130 per cent by 2090.

There is high confidence that climate change would result in a harsher fire weather climate in the future; however, there is low confidence in the magnitude of the change, largely due to the uncertainty associated with rainfall projections (CSIRO and BoM 2015b).

Sea level rise

CSIRO and BOM (2015b) state that there is very high confidence that sea levels would continue to rise during the 21st century.

By 2030, projections are similar for 'Intermediate' and 'High' emissions scenarios, with sea levels for Sydney projected to rise by 0.09 metres to 0.18 metres under an 'Intermediate' emissions scenario, and by 0.10 metres to 0.19 metres under a 'High' emissions scenario. By 2090, projections differ significantly between emissions scenarios. Sea levels along the Sydney shoreline are projected to rise by 0.30 metres to 0.65 metres under an 'Intermediate' emissions scenario, and by 0.45 metres to 0.88 metres under a 'High' emissions scenario.

Flood modelling for the project (**Chapter 17** (Flooding and drainage) and **Appendix Q** (Technical working paper: Surface water and flooding)) has considered the impact of future sea level rise using the 2009 NSW Government *Sea Level Rise Policy Statement* planning benchmarks of 0.4 metres by 2050 and 0.9 metres by 2100 (relative to 1990 mean sea level) (NSW Government 2009).

In its Flood Risk Management Guide: Incorporating Sea Level Rise Benchmarks in Flood Risk Assessments (NSW Department of Environment, Climate Change and Water 2010), the NSW Government recommended that these benchmark rises should be used to assess the sensitivity of flood behaviour to future sea level rise. It is acknowledged that the NSW Government Sea Level Rise Policy Statement has since been repealed. However, in the absence of other formal state or Australian Government policy on sea level rise benchmarks, the previously recommended benchmarks have been adopted to assess the impacts of future climate change on flooding conditions in the vicinity of the project.

Use of these benchmarks, which represent an average sea level rise for NSW, is considered to be a conservative approach, as sensitivity testing undertaken for the project for up to 0.9 metres of sea level rise, is more conservative compared with the current CSIRO and BoM (2015) projections for Sydney, which project up to 0.88 metres of sea level rise by 2090 under a 'High' emissions scenario.

Extreme sea level

CSIRO and BOM (2015b) have calculated a 'vertical allowance' for extreme sea level, which is the minimum distance required to raise an asset to maintain the current frequency of breaches under projected sea level rise. The allowance takes into account the nature of extreme levels along the coastline, influenced by factors such as astronomical tides, storm surges and wind waves. This is the parameter that should be used in planning along the coastline.

For 2030, the vertical allowance for the Sydney shoreline ranges from 0.14 metres under an 'Intermediate' emissions scenario to 0.15 metres under a 'High' emissions scenario. For 2090, the vertical allowance for the Sydney shoreline ranges from 0.59 metres under an 'Intermediate' emissions scenario to 0.84 metres under a 'High' emissions scenario.

As discussed in the previous section, sea level rise benchmarks incorporated in the flood risk assessment for the project are conservative in comparison to current sea level rise and extreme sea level rise projections, with a benchmark of up to 0.9 metres of sea level rise by 2100 used in the sensitivity testing undertaken for the project.

Increase in atmospheric carbon dioxide

The current concentration of atmospheric carbon dioxide (CO_2) is around 400 parts per million (United States' National Oceanic and Atmospheric Administration 2015). The 'High' emissions scenario (RCP8.5) represents a future with little curbing of emissions, with CO_2 concentration continuing to rise rapidly, reaching around 940 parts per million by 2100. Under an 'Intermediate' emissions scenario (RCP4.5), CO_2 concentrations peak at around 2040 and stabilise at around 540 parts per million by 2100.

24.3 Assessment of potential construction impacts

24.3.1 Risk evaluation

Climate change projections for the near future (2030) represent an average of projections for the period 2020–2039. Projections for the near future are considered relevant to the project's proposed construction timeframes, planned for the period between 2018 and 2023. Scientific evidence also demonstrates that Australia is already experiencing impacts from climate change, as discussed in **section 24.2**.

Project construction may be susceptible to climate change impacts, including changes in the frequency of air temperature extremes, changes in mean and extreme rainfall, and changes in the frequency and intensity of storm events. **Table 24-4** identifies potential climate change risks to project construction, with a risk rating of medium or higher.

Table 24-4 Climate change risks to project construction (2030)

Risk scenario	Risk rating
Increase in the intensity and frequency of extreme rainfall leads to localised flooding of project construction sites and ancillary facilities, resulting in delays to project program.	Medium
Increase in the intensity and frequency of storm events leads to unsuitable conditions for undertaking construction works, requiring stop work procedures to be implemented for the safety of construction personnel, resulting in delays to project program.	Medium
Increase in frequency and intensity of extreme heat events increases the risk of heat stress conditions for construction personnel, resulting in increased work health and safety risks and potential delays to project program.	Medium

24.4 Assessment of potential operational impacts

Road networks and infrastructure assets are exposed and vulnerable to climate change because of their long design life, during which many impacts of climate change are likely to become more significant.

The main impacts relevant to these assets are associated with an increase in the intensity of extreme rainfall (which can increase the risk of flooding or landslides and exacerbate damage to pavements), and sea level rise (which is likely to exacerbate coastal erosion, cause an increase in storm surges and coastal flooding and may eventually lead to long-term inundation and loss of land). The largest impacts are likely to be borne by surface roads in low-lying areas or those with steep gradients, and by coastal infrastructure in areas exposed to coastal erosion and storm surges.

24.4.1 Risk evaluation

As discussed in **section 24.1.3**, high and extreme risks identified in the detailed risk assessment should be addressed. Subsequently, a detailed risk assessment would be undertaken during detailed design, any risks rated medium or higher have been retained for further consideration.

The detailed risk assessment (**Appendix X** (Climate change risk assessment framework)) identified a total of 33 direct and indirect risks to the project. Of these risks, the detailed risk assessment identified one extreme, four high and 12 medium risks. These risks are listed in **Table 24-5**. Risks rated as low and negligible are provided in the full risk assessment in **Appendix X** (Climate change risk assessment framework).

Table 24-5 Climate change risks to project operation (2030 to 2090) ranked extreme, high and medium

Risk scenario	Risk rating
Extreme rainfall and sea level rise	
Increase in the intensity and frequency of extreme rainfall, combined with sea level rise (and increased extreme sea levels during storm surges) leads to exacerbated localised flood risks at the Rozelle interchange surface road connections and the new intersection at The Crescent and Victoria Road/Anzac Bridge.	Extreme
Increase in the intensity and frequency of extreme rainfall, combined with sea level rise (and increased extreme sea levels during storm surges) adversely affects performance of surface drainage system at the Rozelle interchange surface road connections and the new intersection at The Crescent and Victoria Road/Anzac Bridge due to increased runoff, leading to localised flooding of surface roads, and potential flooding of ancillary infrastructure, landscaped areas and within the project tunnels.	High
Increase in the intensity and frequency of extreme rainfall, combined with sea level rise (and increased extreme sea levels during storm surges) leads to an intrusion of saltwater into bioretention basins, such as the wetland proposed as part of the project at the Rozelle Rail Yards and the bioretention facility within the informal car park at King George Park, adjacent to Manning Street at Rozelle, proposed for the Iron Cove Link as part of the project.	Medium
Increase in the intensity and frequency of extreme rainfall, combined with sea level rise (and increased extreme sea levels during storm surges) leads to exacerbated localised flood risks at the Hawthorne Canal, Whites Creek, Dobroyd Canal (Iron Cove Creek) and Cooks River.	Medium
Increase in the intensity and frequency of extreme rainfall adversely affects performance of surface drainage system in the vicinity of the Iron Cove Link at Victoria Road and local road upgrades due to inundation, leading to localised flooding of surface roads and through the tunnel outlet.	Medium
Increase in the intensity and frequency of extreme rainfall, combined with sea level rise (and increased extreme sea levels during storm surges) adversely affects performance of surface drainage system in the vicinity of intersections, ancillary infrastructure, substations, landscaped areas, and tunnel outlets.	Medium

Risk scenario	Risk rating
Increase in the intensity and frequency of extreme rainfall adversely affects performance of tunnel drainage system due to increased groundwater infiltration, leading to reduced capacity of drainage sump and pumping system and subsequent localised tunnel flooding.	Medium
Sea level rise causes reduced performance or failure of the water treatment system (culverts, pumping stations) due to increased water levels at the location of the submerged discharge infrastructure at Alexandra Canal and Hawthorne Canal and deterioration from saline intrusion.	Medium
Sea level rise causes reduced performance or failure of water treatment system due to increased water levels at the location of the submerged discharge infrastructure at Rozelle Bay and deterioration from saline intrusion.	Medium
Increase in the intensity and frequency of extreme rainfall, combined with sea level rise, leads to exacerbated risk of flooding to bicycle and pedestrian facilities such as the Bay Run, connections at City West Link/The Crescent/Victoria Road/Anzac Bridge at Rozelle and at other surface portal locations.	Medium
Increase in the intensity and frequency of extreme rainfall, combined with sea level rise (and increased extreme sea levels during storm surges) leads to exacerbated risk of power outages (including subsequent pumping station failure) due to increased flooding.	Medium
Increase in the intensity and frequency of extreme rainfall leads to exacerbated risk of road incidents and increases the safety risk for operational personnel and road users.	Medium
Extreme heat	
Increase in frequency and intensity of extreme heat events causes power outages due to spikes in energy demand across the grid for cooling systems.	High
Increase in frequency and intensity of extreme heat events increases the risk of heat stress conditions for operational personnel.	Medium
Increase in frequency and intensity of extreme heat events leads to reduced efficiency of power generation and transmission, resulting in increased electricity consumption.	Medium
Bushfire	
Increased frequency and intensity of bushfire events leads to failure of communications network due to fire damage to network infrastructure and indirect impacts on the project through communications outages.	High
Increased frequency and intensity of bushfire events leads to failure of power supply infrastructure due to fire damage to the energy transmission network and indirect impacts on the project through power outages.	High

An assessment of potential cumulative impacts on climate change risk during project operation is provided in **Chapter 26** (Cumulative impacts).

Post-adaptation residual risk levels for extreme and high risks are discussed in **Chapter 28** (Environmental risk analysis). Adaptation measures for medium risks would be considered further during detailed design and implemented where reasonable and feasible.

24.5 Management of impacts

24.5.1 Adaptation for climate change

Adaptation measures to address climate change risks that are incorporated in the project design at this stage include broader design refinements and opportunities for optimisation. These refinements have been made based on best practice design, with assessment against multidisciplinary criteria. Consideration has been given to avoiding, minimising or managing risks from future climate change, where possible.

As discussed in **section 24.4**, key climate change risks for the project are associated with an increase in the intensity of extreme rainfall and sea level rise, which are likely to exacerbate the existing flood risk experienced in some project locations, particularly the intersection of The Crescent and City West Link at Rozelle. In order to assess the impact of climate change on flood behaviour, sensitivity analyses were undertaken for increases in extreme rainfall and sea level rise (see **section 24.2.2**), with design refinements made to manage potential flood risks and flood risks likely to be exacerbated by climate change. These refinements, and design refinements which address additional climate change risks, are outlined in the following points.

Construction

- The indicative layouts of the temporary construction ancillary facilities have taken into consideration the flood risk posed to the land, including increased flood risk due to climate change. This includes identifying opportunities to provide setback from areas at risk of flooding, locating uses considered more disruptive or vulnerable to flooding - such as stockpile areas, chemical storage areas, tunnel dives and deep excavations - away from areas of highest risk, and allowing controlled flooding of suitable areas such as car parks, where feasible. Refer to **Chapter 17** (Flooding and drainage) and **Appendix Q** (Technical working paper: Surface water and flooding) for further detail.

Operation

- Refinement and revision of the alignment of the proposed future Western Harbour Tunnel and Beaches Link ramps reduces exposure of portals and surface connections to potential impacts from sea level rise and flooding from extreme rainfall at the existing intersection of The Crescent and City West Link
- Due to the high risk of flooding posed to the Rozelle interchange, the road design has been heavily influenced by flood risk and drainage considerations through its evolution. As part of the design development and refinement, design options for the Rozelle interchange were revised to include tunnel connections which extend underground beyond the boundaries of the Rozelle Rail Yards site. Refer to **Chapter 17** (Flooding and drainage) and **Appendix Q** (Technical working paper: Surface water and flooding) for further detail regarding the flood assessment for the Rozelle interchange. Figures in section 6.2.2 of **Appendix Q** (Technical working paper: Surface water and flooding) show the potential climate change impact on peak flood depths for the Probable Maximum Flood (PMF) and 100 year ARI events for the Rozelle interchange
- The design of the operational sites has taken into consideration the flood risk posed to the sites and how to manage these risks, as appropriate. The process for establishing flood risk for the project is outlined in **Chapter 17** (Flooding and drainage). This has meant that mitigation measures are already included as a consequence of the evolution of the project design, as discussed in **Chapter 17** (Flooding and drainage) and **Appendix Q** (Technical working paper: Surface water and flooding)
- Tunnel portals have been designed to ensure immunity from the greater of the PMF or 100 year Average Recurrence Interval (ARI) event plus 0.5 metre freeboard. Where the portals lie within the PMF extent, this would be achieved by appropriate flood protection measures. Refer to management measures in **Chapter 17** (Flooding and drainage) and **Appendix Q** (Technical working paper: Surface water and flooding) for further detail
- To accommodate increased flows as a result of the project, the design includes upgrade of the intersection of City West Link and The Crescent, including realigning The Crescent bridge structure over Whites Creek and naturalisation of the section of Whites Creek between the bridge and Rozelle Bay. The new bridge structure has been designed to include a second span over a

landscaped overflow area to increase the capacity of Whites Creek during large flood events. Figures in section 6 of **Appendix Q** (Technical working paper: Surface water and flooding) showing the design flood behaviour for key project components

- Upgrade of drainage infrastructure discharging from Rozelle Rail Yards under City West Link to Rozelle Bay has been incorporated in the design, including provision of three flood channels and a culvert arrangement with increased capacity to accommodate flows from the Rozelle Rail Yard drainage upgrades. The outfall includes a tide gate to minimise tidal intrusion and improve durability of the Rozelle Rail Yards drainage system (refer to **Appendix Q** (Technical working paper: Surface water and flooding))
- Design of landscape topography at Rozelle Rail Yards to consider increased flood risk from extreme rainfall events. These areas have been designed to act as additional waterway areas and flood storage, to minimise impacts in extreme rainfall events (refer to **Appendix Q** (Technical working paper: Surface water and flooding))
- Provision of a constructed wetland and additional bioretention treatment facilities (where space and grade allow) within the Rozelle Rail Yards site, designed to receive and treat stormwater runoff from the Rozelle Rail Yards as well as groundwater effluent from the water treatment plant (refer to **Appendix Q** (Technical working paper: Surface water and flooding))
- Development of design options for stormwater treatment for the Iron Cove Link, with a bioretention facility within the informal car park at King George Park adjacent to Manning Street at Rozelle. Detailed design of the bioretention facility would consider the impact of future climate change on rainfall intensities. Further detail regarding the drainage design for the Iron Cove Link is provided in **Appendix Q** (Technical working paper: Surface water and flooding)
- Consideration of increased extreme heat events has been incorporated into the urban design of project surface infrastructure and areas of open space created by the project, including landscaped areas to increase shading and areas of respite and reduce the absorption of heat by infrastructure, where possible
- The design reduces power consumption associated with tunnel ventilation by locating the ventilation facilities close to the mainline tunnel portals, thereby optimising the piston effect generated by vehicles
- Backup power and other redundancy measures have been built in to ensure temporary continuity of powered infrastructure in the event of a power outage
- Project infrastructure has been designed for long term performance and durability of structures, increasing asset design lives and reducing the frequency of maintenance activities.

24.5.2 Next steps for adaptation

This initial climate change risk assessment would inform a detailed climate change risk assessment, which will be undertaken during detailed design, in accordance with AS 5334-2013 Climate change adaptation for settlements and infrastructure - A risk based approach. The assessment will identify and implement adaptation measures to address high and extreme risks. The decision to implement adaptation measures for medium risks will also be considered during detailed design.

Table 24-6 lists recommended next steps for the development of adaptation options to be further considered during detailed design and the further detailed climate change risk assessment.

Table 24-6 Environmental management measures – climate change risk and adaptation

Impact	No.	Environmental management measures	Timing
Impacts of climate change	CC1	In the refinement of construction Work Health and Safety Management Plans, consider the increased potential for heat stress among construction personnel and implement measures for greater awareness and education of personnel around health and wellbeing during periods of extreme heat.	Construction
	CC2	This initial climate change risk assessment would inform a detailed climate change risk assessment, which will be undertaken during detailed design, in accordance with AS 5334-2013 Climate change adaptation for settlements and infrastructure - A risk based approach. The assessment will identify and implement adaptation measures to address high and extreme risks. The decision to implement adaptation measures for medium risks will also be considered during detailed design.	Construction
	CC3	Adaptation measures will be identified and implemented to address high and extreme climate change risks. Adaptation measures for medium risks will also be considered further during detailed design and implemented where reasonable and feasible.	Construction
	CC4	The impact of climate change on potential flood risks will be considered during development of the detailed design in accordance with relevant guidelines as described in **Chapter 17** (Flooding and drainage) and **Appendix Q** (Technical working paper: Surface water and flooding).	Construction
	CC5	Increased flood risks due to climate change will be considered in the detailed design of drainage systems. Drainage network features will be developed and installed to mitigate potential increased flood risks as described in **Chapter 17** (Flooding and drainage) and **Appendix Q** (Technical working paper: Surface water and flooding).	Construction
	CC6	Potential changes to sea levels due to climate change will be considered during the design of operational water treatment plants that will discharge to waterways. Discharge outlets and relevant plant features will be designed and constructed accordingly.	Construction
	CC7	Consider the projected increase in the intensity and frequency of extreme rainfall during detailed design, which may lead to exacerbated risk of road incidents. Consider implementation of operational procedures for surface connections to increase safety during extreme rainfall events, such as use of variable speed signs and reduced speed limits.	Construction and operation

Note:

During the consideration of any the above adaptation options, analyses of costs and benefits should be undertaken.