M5 Motorway Westbound Traffic Upgrade

Climate Risk Assessment

Transport for NSW

Reference: 509608

Revision: 1

2022-08-17

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Document control record

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Document control						aurecon
Report title		M5WBU Climate Risk Assessment				
Document code			**Project number**			
File path		Https://aurecongroup.sharepoint.com/sites/509608/5 Deliver Design/508 Environment/Technical specialist studies/Final submission/Climate risk assessment/M5WBU Climate Risk Assessment.docx				
Client		Transport for NSW				
Client contact		Paul Nicholls	**Client reference**			
Rev	**Date**	**Revision details/status**	**Author**	**Reviewer**	**Verifier** (if required)	**Approver**
0	2022-08-08		N Leybourn	E Worthington		CMcC
1	2022-08-17		N Leybourn	E Worthington		CMcC
Current revision		**1**				

Approval			
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1 Summary

Transport for NSW proposes to upgrade the M5 Motorway westbound between Moorebank Avenue and the Hume Highway, Casula. The proposal involves improving connectivity and safety between the M5 Motorway and the Hume Highway. The proposal would also include the upgrade of the M5 Motorway intersection with Moorebank Avenue, in Moorebank.

This report details the process carried out to assess and evaluate climate-related risks to the proposal. This includes:

- Adopting an appropriate climate scenario across the lifetime of the managed assets
- Defining the scope of the assessment, identifying, and rating relevant risks.

Transport infrastructure assets are long-lived and highly exposed to climate-related risk. Climate change risk assessments of such infrastructure typically involves identifying climate risks and canvassing appropriate adaptation actions to reduce ‘high’ and ‘extreme’ risks. This approach aligns with the AS 5334-2013 Australian Standard *Climate Change adaptation for settlements and infrastructure* (AS 5334), which has been adopted for the purposes of this assessment. We note the AS 5334 differs from the TfNSW Baseline Sustainability Requirements which require that ‘high’ and ‘very high’ risks be addressed.

The extremely localised scope of this climate risk assessment, focused on the M5 Motorway Westbound Traffic Upgrade, resulted in no extreme and very few high risks being identified. The high risks primarily relate to extreme rainfall events and associated storm surge and flooding impacts; however, adaptation to mitigate these risks has already been carried out through the inclusion of the impact of climate change in the Hydrology and Flooding Assessment (Aurecon, 2022), and the Surface Water and Groundwater Technical Assessment (Aurecon, 2022). These adaptation measures consider changes to the environment from the proposal, including clearing vegetation and constructing new structures. Implementation of the report recommendations to the final design of the proposal would reduce the residual risk associated with extreme rainfall to moderate.

The risks associated with extreme rainfall events have potential to be further reduced through the inclusion of a design buffer beyond 1% Annual Exceedance Probability (AEP) in the structures’ final design. This would also account for any under-estimation of flood and storm surge risk associated with the use of NSW and Australian Regional Climate Modelling (NARCliM) 1.0 data as the basis for the climate change aspects of the Surface Water and Groundwater Technical Assessment. NARCliM 1.0 is an older dataset that yields rainfall, runoff and recharge estimates somewhat lower than more recent CSIRO and Bureau of Meteorology (BoM) climate projections. In addition, a higher AEP would allow a buffer for resilience, recognising that we do not understand the full extent of climate change impacts on natural systems.

The other high risks identified in the risk assessment are associated with the predicted increase in extreme heat events. Some might be reduced through changes to the final design, such as providing shade for the shared use access path. However, there is a limit to which these risks can be economically mitigated, given the nature of the design. It is therefore likely that the proposal would contribute to, and be impacted by, increasingly severe urban heat island effects.

The relatively limited number of business as usual (BAU) high risks, and absence of extreme risks, does not account for regional levels of risk; a risk assessed as low at a local level may be moderate or high at a regional level, as the greater scope of the regional assessment would increase the probability of the event occurring. The proposal is likely to be impacted by climate change in the broader context of Sydney’s road network. A network level risk assessment would address broader regional risk impacts to the proposal.

2 Introduction

2.1 Project description

Transport for NSW proposes to upgrade the M5 Motorway westbound between Moorebank Avenue, Moorebank and the Hume Highway, Casula. The proposal would ease congestion by improving connectivity between the M5 Motorway and the Hume Highway.

Key features of the proposal (Figure 1) include:

- A new two lane westbound M5 Motorway exit for Hume Highway traffic, located about 1.5 kilometres east of the existing Hume Highway exit. The exit ramp would include:
  - A grade separated underpass beneath Moorebank Avenue
  - A two-lane 290-metre-long bridge over the Georges River, Southern Sydney Freight Line, and then T2 Inner West & Leppington and T5 Cumberland rail lines
- Removal of the current M5 Motorway westbound Hume Highway exit
- Upgrade of the Moorebank Avenue westbound entry ramp maintaining access to the M5 Motorway and Hume Highway
- A new shared path on the southern side of the new Hume Highway exit ramp from Moorebank, across the Georges River on the new bridge and connecting to the Hume Highway and Lakewood Crescent
- Installation of new drainage infrastructure including:
  - Kerb and gutters, pits and pipes
  - Installation of a new operational spill basin under the new bridge, east of the Georges River
  - Removal of the existing spill basin near Yulong Close, Moorebank
- Intelligent Transport Systems (ITS) including installation and adjustment to traffic/SCATS detection, CCTV, a web camera an emergency breakdown telephone and stopping bay, variable message signs (VMS) and backbone conduit
- Ancillary work associated with the proposal including:
  - Relocating, adjusting, or protecting existing utility services that conflict with the proposal
  - Installation of new street lighting and various road furniture
  - Delineation including signage, line-marking and other items to facilitate road user safety of the new infrastructure
  - Landscaping
  - Property adjustments where necessary

Construction is expected to take about 40 months to complete across a staged approach of six construction areas.

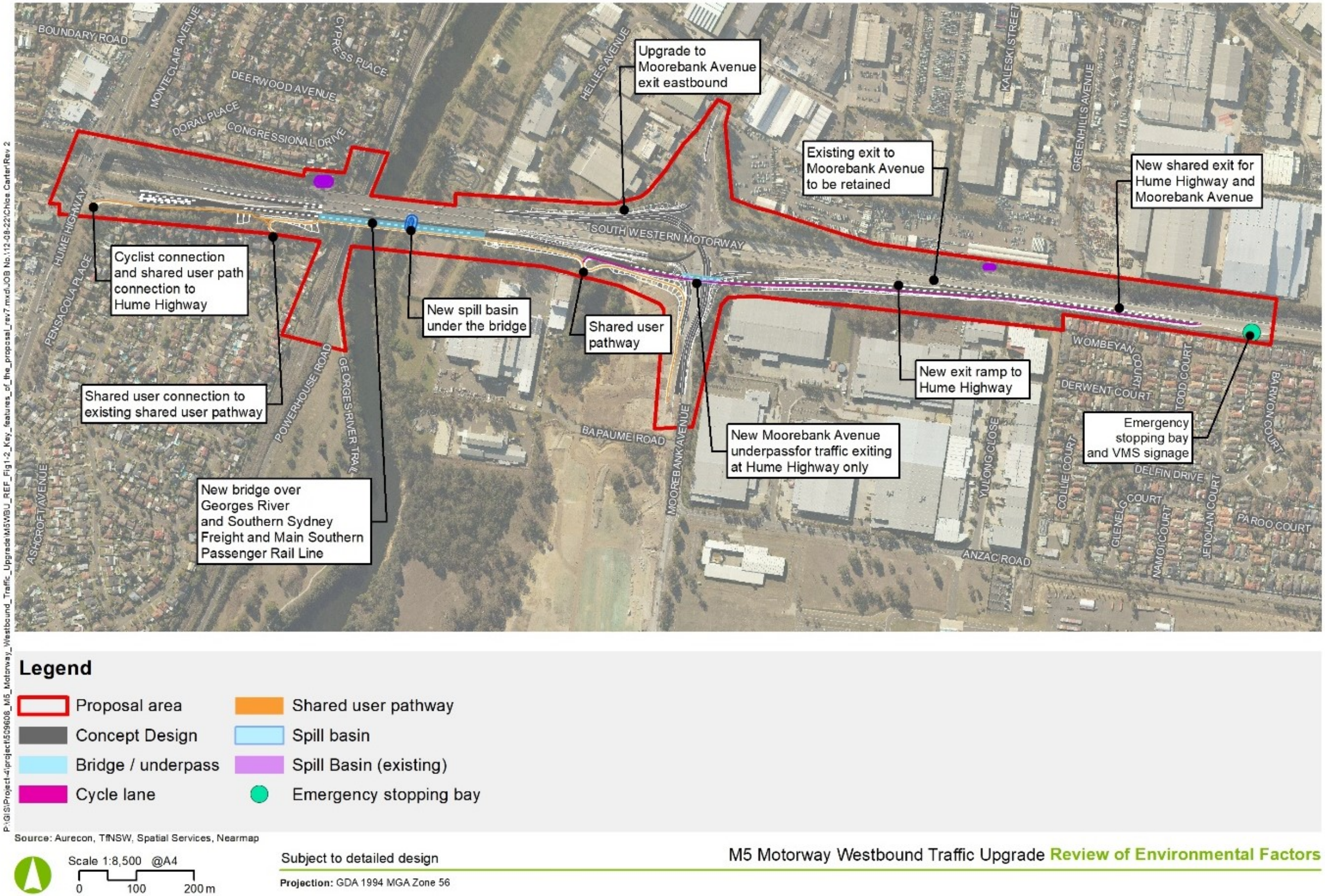

Figure 1 Key features of the proposed M5 Motorway Westbound Traffic Upgrade

2.2 Purpose

This report details the initial climate risk assessment carried out for the M5 Motorway Westbound Traffic Upgrade as part of the Review of Environmental Factors (REF).

2.3 Approach

The risk assessment approach used aligns with the AS 5334-2013 Australian Standard for Climate change adaptation for settlements and infrastructure, and the Transport for NSW Climate Risk Assessment Guidelines.

Risk assessment activities are detailed in this report as follows:

- **Section 3** details the risk assessment context, including legislative and policy settings and relevant climate change projections.
- **Section 4** summarises the risk assessment itself, including the process of establishing the scope of the assessment, identifying climate hazards under the chosen climate projection, identifying and rating climate risks. The final risk register is summarised in this section.
- **Section 5** summarises adaptation action for those risks rated as high, and the impact of these actions on the residual risk.

3 Risk assessment context

The following contextual information was considered when establishing the scope of the risk assessment and identifying climate change hazards and associated risks.

3.1 Organisational context

3.1.1 Policy and legislation

Federal and State legislation creates obligations for Transport for NSW to assess, disclose and manage climate risks through its works. These are outlined in Table 1.

Table 1 Climate change legislative, policy and guidance applicable to M5 Motorway Westbound Traffic Upgrade

Legislation / policy / guidance	Obligation / recommendation
Federal *Work Health and Safety Act 2011*, and NSW enabling legislation	Transport for NSW has a range of risk management obligations under State and Federal legislation and standards to guarantee the safety of assets and operations. It also has obligations under the *Work Health and Safety Act 2011* to limit risk to the health and safety of staff, road users and other persons through its works.
Asset Management Policy for the NSW Public Sector (TPP 19-07), 2019	Requires that Asset Management Plans include "*an assessment of the resilience and vulnerability of the agency's assets to the impacts of climate change …and proposed mitigations/interventions*".
NSW Climate Change Policy Framework, 2016	A key objective of this policy is to make NSW more resilient to a changing climate by: ▪ Assessing and effectively managing climate change risk to government assets and services ▪ Reducing risks and damage to public and private NSW assets arising from climate change ▪ Reducing climate change impacts on health and wellbeing ▪ Managing climate change impacts on natural resources, ecosystems and communities.
NSW Critical Infrastructure Resilience Strategy, 2018	Promotes improving infrastructure, organisational and community resilience. The strategy's scope includes natural, technological and malicious hazards and focuses on improving adaptation to long-term stresses such as climate change.
NSW Climate Change Adaptation Strategy	The strategy sets out key decision-making principles and objectives for adaptation, key priorities and a suite of actions, these include: ▪ Develop robust and trusted metrics and information on climate change risk ▪ Complete climate change risk and opportunity assessments ▪ Develop and deliver adaptation actions plans ▪ Embed climate change adaptation in NSW Government decision-making.
Transport for NSW's Environment and Sustainability Policy, 2020	This policy outlines a collective commitment to delivering environmental and sustainability outcomes across the Transport cluster and outlines the methodology Transport for NSW will use to meet its commitments to economic prosperity and social inclusion in an environmentally responsible and sustainable manner.
Transport Sustainability Plan, 2021	Creates a common framework for Transport to define continuous improvement in integrated sustainability. Contains eight focus areas that address the most important sustainability aspects associated with the activities of Transport. Focus Area 1 is *Respond to Climate Change*, and sets out the goal to *consider climate risks in all decisions.*
Transport for NSW Sustainable Design Guidelines, 2017	One of the aims of the guideline is developing, expanding, and managing a transport network that is sustainable and climate resilient. In line with the United Nations Sustainable Development Goals, the guidelines require the completion of a climate risk assessment.
Future Transport 2056	Sets out that Transport for NSW will consider resilience, including climate resilience, in the planning and design of all assets and services. A climate change risk assessment should be developed for assets as part of the whole-of-life impact assessment when developing projects.

Legislation / policy / guidance	Obligation / recommendation
Transport for NSW Climate Risk Assessment Guidelines, 2021	These guidelines were developed to provide Transport for NSW Project Teams, Alliance partners, contractors, and other internal and external stakeholders with practical "how-to" advice and requirements on conducting a Climate Risk Assessment (meeting the requirements of Transport for NSW Sustainable Design Guidelines).

3.2 Climate change context

Climate change both creates and multiplies risks to infrastructure, people, the environment, and the economy. Increasingly frequent and severe extreme events already impact the operation and maintenance of transport assets. These extreme events are likely to increase in a climate-affected future and be compounded by the impacts of chronic climate change.

Most transport assets have long design lives and were built to standards defining their ability to safely operate under historical climate conditions. Under projected climate change models, the climate assumptions underlying these standards no longer hold true, meaning many of these assets may not be able to safely operate for their full intended design life.

Figure 2 shows the growing gap between the climate anticipated in design standards and the climate likely to be experienced by assets under low and high emissions scenarios. Note that this analysis suggests that, even under a low-emissions scenario, assets designed to historic standards are likely to fall short of AS 5334 necessary to withstand future climate conditions.

Managing the likely future impacts of climate change on new transport infrastructure, like the proposed M5 Motorway Westbound Traffic Upgrade, requires understanding of the timing and likelihood of climate risks, and how these intersect with asset maintenance and renewal timeframes. This climate risk assessment considered these factors in the context of the worst-case climate change scenario (RCP8.5).

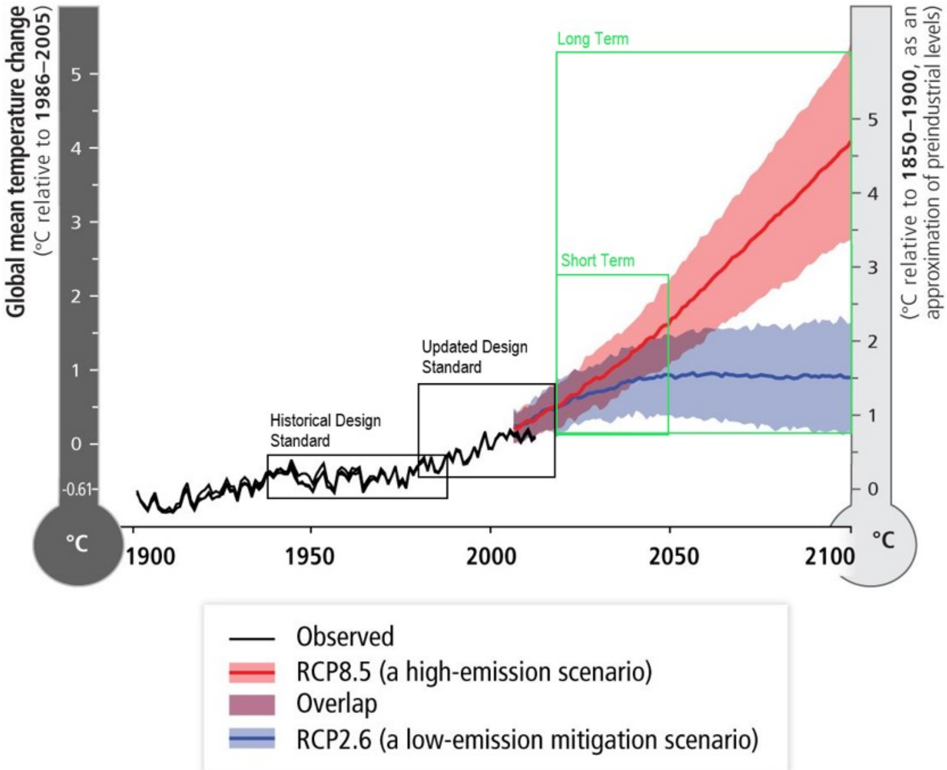

Figure 2 **Relationship (and likely gap) between historical and updated design standards currently is use, and two potential climate scenarios. The RCP8.5 scenario is used for the M5 Motorway Westbound Traffic Upgrade climate risk assessment (Aurecon 2022)**

3.2.1 Historic climate

Observed extreme climate events

Sydney's climate is already changing, and the frequency and severity of extreme events increasing. Over the last three years, Sydney has experienced:

- Extreme rainfall and flooding repeatedly in 2022
- An extreme heatwave in 2021
- The Black Summer bushfires in 2019-2020, which were the worst recorded in NSW.

Each of these events impacted Sydney's transport infrastructure, causing damage and operational disruption. The extreme rainfall and flooding in 2022 caused extensive road pavement and sub-surface damage, and damaged slopes and retaining structures. During severe storms, soil became water-logged, and trees were downed on roads and other transport infrastructure.

Similarly, the extreme heatwave in 2021 and the Black Summer bushfires caused road surfaces to buckle and melt and transmission lines to sag. Electrical systems were also interrupted by power outages and bushfire impacted power transmission infrastructure.

Historical temperatures

Temperatures across Australia, and particularly across the south-east coast, have increased with mean temperatures increasing by approximately 0.8°C over the last century (CSIRO, 2022). A historical warming trend is evident in NSW since 1910 (Figure 3). The recent decades have been the warmest on record for both mean, maximum and minimum average temperatures (CSIRO, 2022).

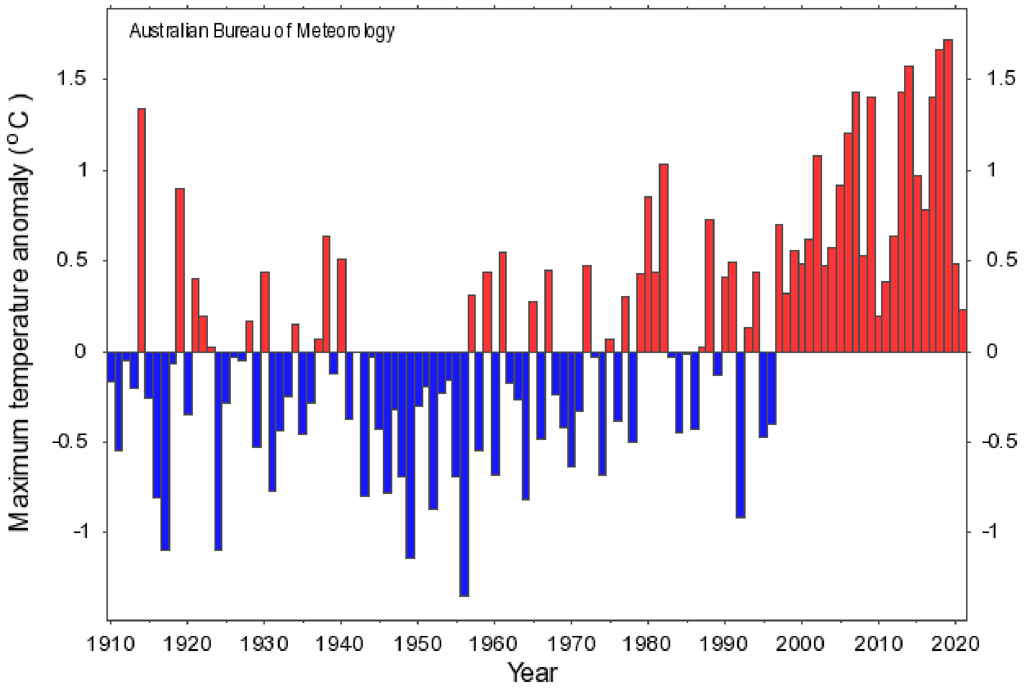

Figure 3 Annual maximum temperature anomaly (the departure from a reference value or long-term average), for south eastern Australia 1910 - 2021, based a 30yr average from 1961 – 1990 (BoM 2022)

Weather records from Bankstown Airport AWS (Bureau of Meteorology (BoM) site 066137) highlight the increasing frequency of hot days over the last decade for the region that includes the M5 Motorway Westbound Traffic Upgrade. This is evident when comparing average days per year above 35°C and 40°C from 1981-2010 against 1991-2020 in Figure 4.

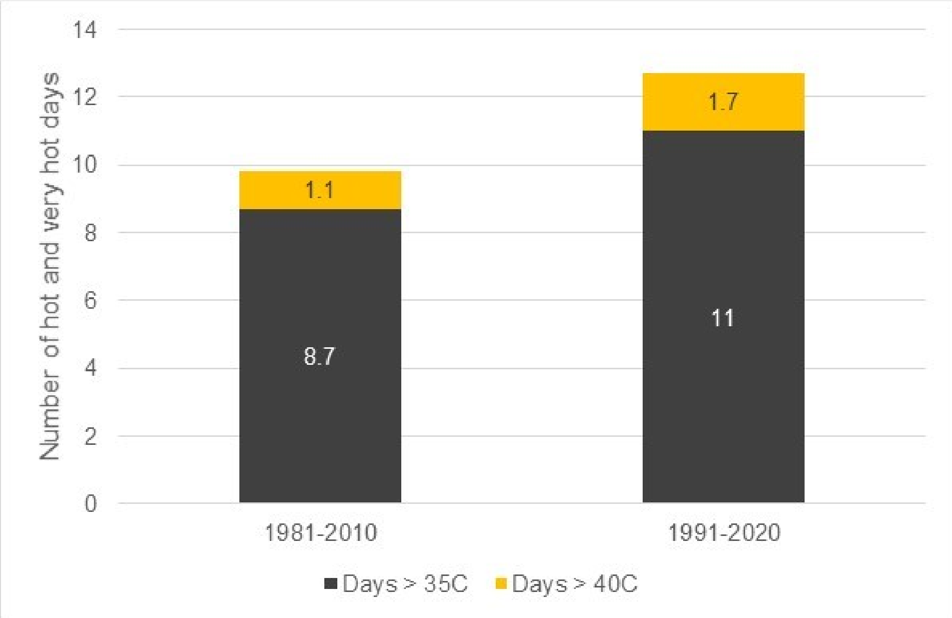

Figure 4 Historical hot days from 1981-2010 and 1991-2020 for Bankstown Airport

Historical fire weather

There has been a long-term increase in extreme fire weather and the length of the fire season across large parts of Australia since the 1950s. Observed changes in southern and eastern Australia include more extreme conditions during summer, as well as an earlier start to the bushfire season with dangerous weather conditions occurring significantly earlier in spring than they used to.

Historical rainfall

Average rainfall across the proposal area has been decreasing over the last decade. This decrease is evident when comparing average totals from 1981-2010 against 1991-2020 for Bankstown Airport AWS (Table 2).

Table 2 Bankstown historical average rainfall trend

Attribute	Bankstown	
	1981-2010	1991-2020
Mean Annual Rainfall (mm)	858.6	791.7
Highest Annual Rainfall (mm)	1397.8	1052.6
Lowest Annual Rainfall (mm)	493.4	493.4

Despite this overall drying trend, the severity of extreme rainfall events and storms has increased. This means that it rains less frequently overall, but when it does rain, far more rain is delivered in a single event than the historical average would suggest. Figure 5 shows the cumulative rainfall received at Parramatta to April 2022 compared to cumulative mean rainfall; an unusually high volume of rain has been received by this point in the year.

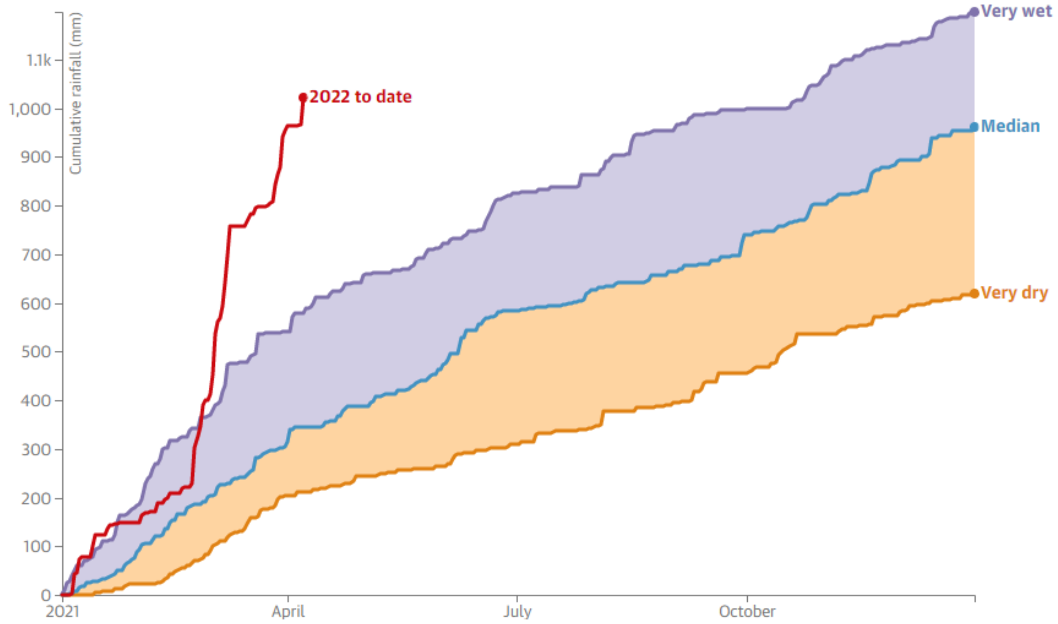

Figure 5 **Cumulative rainfall vs. long term averages, Parramatta, NSW**

Historical sea level rise

Observed sea level in Sydney Harbour has increased 15cm since 1950. While still relatively minor, this trend has been accelerating in recent decades.

Historical atmospheric carbon dioxide

Atmospheric carbon dioxide (CO_2) and CO_2 equivalent (gases that capture radiative energy in the same manner as CO_2) concentrations have been increasing rapidly since the Industrial Revolution a result of fossil fuel use. The increasing atmospheric concertation of CO_2 (and equivalent greenhouse gases) is the primary driver of human induced climate change, the impacts of which are becoming evident in the increasing frequency and severity of extreme weather events, and changes to seasonal weather patterns.

Increasing atmospheric carbon dioxide concentrations have the potential to impact the service life of concrete structures through increasing carbonation. Carbonation occurs when calcium hydroxide and hydrated calcium silicate in exposed concrete faces react with atmospheric CO_2 to form carbonates. The increasing presence of carbonates in concrete structures reduces their mechanical strength. Carbonation also changes the pH of concrete, making it less alkaline and increasing the rate at which steel reinforcements within concrete structures corrode. Higher temperatures, moisture (both humidity and direct immersion) and exposure to salinity all increase the rate at which carbonation and corrosion occur. Historically, carbonation has been managed by applying acrylic or polyurethan sealers to protect concrete.

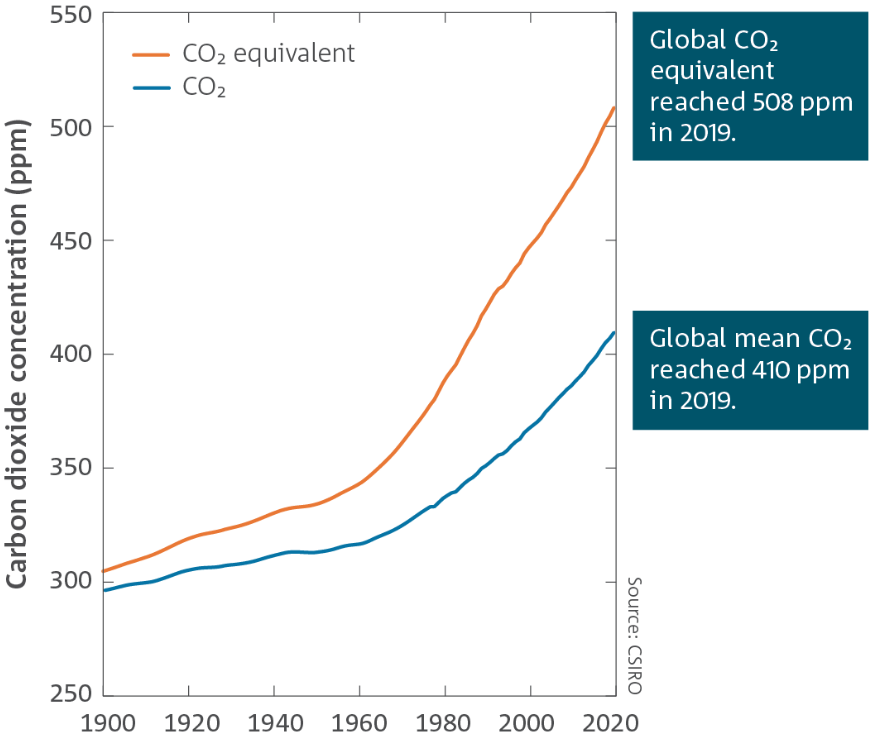

Figure 6 **Global mean CO_2 concentration and global mean greenhouse gas concentrations expressed as CO_2 equivalent (ppm). CO_2 equivalent is calculated from the atmospheric concentrations of carbon dioxide, methane, nitrous oxide and synthetic greenhouses (BoM 2020)**

3.2.2 Future climate

Under climate change, the future climate experienced in south west Sydney is likely to be substantially different to the observed historical climate. The RCP8.5 scenario with a timescale to 2090 has been used to assess the impacts of climate change on the proposal. This is the worst case climate scenario, representing a 'very high baseline emission scenario'. Using this scenario aligns with the requirements of the Transport for NSW CRA Guidelines.

Major climate hazards identified as likely to impact the Liverpool area under this scenario include:

- Bushfires
- Chronic heat
- Extreme heat events
- Extreme rainfall events
- Increased atmospheric CO_2
- Increased humidity.

Climate change projections

Climate change projections to inform the risk assessment were developed for two time periods, reflecting the operating lives of different infrastructure and services:

- **2050:** Assets and systems with short to medium term operating lives such as road pavements surface layers and electronic controls, which are expected to reach end of life in the next 25-30 years
- **2090:** Assets and systems with long operating lives, which in most instances are fixed and on-going features such as structures or drainage

The Intergovernmental Panel on Climate Change's (IPCC's) Fifth Assessment Report (AR5; IPCC, 2013) provides a synthesis of climate change modelling carried out by leading international climate research organisations. Outputs from this work for Australia are published on the Climate Change in Australia (CCIA) website.

The Australian Climate Futures tool (on the CCIA website) was used to help capture the range of projection results relevant to the Liverpool area. The Climate Futures Tool groups data into 'clusters' which largely correspond to the broad-scale climate and biophysical regions of Australia. The East Coast South sub-cluster was used for this assessment as it encompasses the Sydney region.

A summary of climate change projections adopted for the Liverpool area is outlined in Figure 7. These projections provide the basis for the climate change risk assessment for the proposal.

- Average temperatures will continue to increase in all seasons (*very high confidence*)
- More hot days and warm spells are projected with *very high confidence*. Fewer frosts are projected with *high confidence*
- Rainfall changes are possible but unclear
- Increased intensity of extreme rainfall events is projected, with *high confidence*
- Time spent in drought is projected to increase with *medium confidence*
- Mean sea level will continue to rise and height of extreme sea-level events will also increase with *very high confidence*
- A harsher fire-weather climate is forecasted in the future with *high confidence*
- On annual and decadal basis, natural variability in the climate system can act to either mask or enhance any long-term human induced trend, particularly in the next 20 years and for rainfall

Figure 7 Summary climate projections for the East Coast sub-cluster

Summary climate change projections presented in Table 3 are the modelled 50th percentile values under an RCP8.5 scenario for 2050 and 2090 timeframes (CSIRO, 2022). Temperature and rainfall projections are based on the historical record from the Bankstown Airport AWS BoM site 066137, with reference period (1981-2010) climate sequences adjusted by climate change factors for the CCIA East Coast South sub-cluster for 2050 and 2090 (CSIRO, 2022).

Table 3 M5WB climate change projections (RCP8.5) for the Bankstown Airport AWS BoM station

Climate attribute	Reference period (1981 -2010)	2050	2090
Temperature (°C)			
Hottest day	43.1	44.9	46.9
Annual average	17.8	19.5	21.4
Days/yr ≥35°C	4.9	10.9	19.8
Days /yr ≥40°C	0.5	1.3	3.2
Rainfall (mm)			
Mean annual rainfall (range)	868	857 (740.7-943.2)	840 (692.6-1007.9)
Wettest day (1 in 20 yr)	1397.8	1487.15	1577.13
Increase in severe rainfall intensity		9.0%	19.6
Other Variable			
Relative Humidity (% change)		-0.9	-1.5
Evapotranspiration (% change)		7.3	14.3
Solar Radiation (% change)		0.9	1.3
Sea Level Rise (cm)		28	79

Climate attribute	Reference period (1981 -2010)	2050	2090
Average wind speed (% change)		-0.2	-1.1
Atmospheric CO_2 concentration (ppmv)		541	936

Projected temperature changes

The severity and frequency of extreme temperatures and warm spells is projected to continue increasing with climate change in all seasons (Dowdy et al., 2015). Under the RCP8.5 scenario, it is likely that by 2050 the region that the motorway passes through will experience, on average, double the number days each year where temperatures exceed 35°C by 2050 (Table 3).

Overall, projected changes in temperature include:

- Increases in average temperatures
- Increasingly frequent and higher temperature extremes
- More frequent and severe heatwaves
- Increasingly frequent hot days and very hot days (where temperature exceeds 35°C and 40°C respectively)
- Increased evaporation rates.

Temperature changes associated with climate change are considered in the Surface Water and Groundwater Technical Assessment Working Paper (Aurecon, 2022) to inform the design. The scenarios adopted for the Surface Water and Groundwater Technical Assessment suggests that:

> *"Temperature projections for Eastern Australia indicate higher average temperatures for the near future (2030) with the daily average expected to rise between 0.5 and 1.4°C above the average value recorded between 1986 and 2005. By late in the century (2090), for a high emission scenario (RCP8.5) the projected range of warming is 2.8 to 5.0 °C. Under an intermediate scenario (RCP4.5) the projected warming is 1.3 to 2.6 °C (Office of Environment and Heritage, 2014). As average temperatures are predicted to rise in the future because of climate change, evaporation rates can be assumed to rise as well."*

Projected fire weather

Increasing temperatures and extreme heat events are projected to increase the frequency of days with harsher fire weather conditions (high confidence) (Dowdy et al., 2015). The proposal area borders a section of land that burnt during the 2019-2020 Black Summer bushfires.

Fires may damage the road, roadsides and electrical assets, while smoke haze impacts visibility for road users and ground crews. The risk of future direct fire impacts to the proposal is moderated by the Liverpool area being primarily urban with limited connectivity through vegetated areas. However, the risk of reduced visibility due to smoke haze remains high.

Projected rainfall changes

Rainfall patterns are also projected to continue changing with an overall drying trend. Average winter rainfall is projected to decrease throughout south-east Australia (medium confidence) (Dowdy et al., 2015) and changes in other seasons are possible. Autumn and winter are historically when south-east Australia receives most of its rainfall, so alongside loss of cool season rainfall, time spent in drought is projected to increase over the course of the century (medium confidence) (Dowdy et al., 2015).

When rainfall does occur, it is likely to be more intense and extreme (high confidence) (Dowdy et al., 2015). Increasingly frequent and severe rainfall events are likely to flood waterways and cause overland flows that pose risks to transport infrastructure, road users and staff.

Existing natural variability in rainfall for Sydney, and projected climate changed affected rainfall, are influenced by drivers that include the El Niño-Southern Oscillation (ENSO). It is likely that the ENSO will mask or enhance changes in rainfall trends in the short term. For instance, a La Niña phase of the ENSO in 2022 resulted in Greater Sydney's wettest autumn on record (BoM, 2022).

Projected changes to rainfall include:

- Increasingly intense extreme rainfall events and severe storms
- A decrease in average winter rainfall, with possible changes to average rainfall in other seasons
- An increase in the time spent in drought
- The potential for both drier and wetter periods than historically experienced.

The Hydrology and Flooding Assessment (Aurecon, 2022) conducted to inform the design of the proposal has considered the likelihood of increased frequency and severity of extreme rainfall events. The data used in this report is drawn from the Australian Rainfall and Runoff Guidelines (ARR 2019), which are considered the latest available predictions for future climate conditions. ARR 2019 predicts a worst-case increase in rainfall intensity of 9% and 19.7% (20%) for the years 2050 and 2090 respectively. The assessment acknowledges that climate change flow hydrographs were generated in the absence of a hydrological model and involved some estimation that may marginally underestimate the values compared to the typical method.

The Surface Water and Groundwater Technical Assessment Working Paper (Aurecon, 2022) to inform the design also considers the implications of the increasing frequency and severity of extreme rainfall in a climate change-affected future. This assessment identified the trend of increased rainfall intensities and noted that higher intensity storms will result in higher runoff volumes, whereas increased evaporation rates will likely lead to reduced groundwater recharge. However, this assessment was carried out against NARCliM datasets, which are older and predict somewhat lower rainfall extremes than more current CSIRO and Bureau of Meteorology projections would suggest.

The Surface Water and Groundwater Technical Assessment Working Paper notes that:

> "*runoff volume from the proposal area to receiving surface watercourses will increase, although the quantum of change is difficult to determine. The speed with which stormwater will reach these receiving watercourses is also likely to increase, due to lower interception, leading to a flashier hydrological response to rainfall. It is predicted that recharge to groundwater which would reduce groundwater table levels in the near future will decrease which may in turn have a reduction in base flow of the Georges River. That, paired with higher surface runoff rates, would create a situation of greater variability in river water levels. In the far future, recharge levels are expected to increase, thus creating overall higher groundwater levels.*"

Sea level rise

Mean sea level rise is projected with very high confidence to continue to rise along with the height of extreme sea-level events (wave heights and storm tide inundation). In Australia the average rate of relative sea level rise from 1966-2009 has been observed at 1.4mm/year (CSIRO, 2022). However, the rate of sea level rise from 1993-2017 has been higher along the south-east coast than along other regions of Australia's coastline.

The impact of sea level rise has been modelled in the Hydrology and Flooding Assessment (Aurecon, 2022). This assessment adopted an allowance of 0.4 metres and 0.9 metres for sea level rise for the years 2050 and 2100 respectively, based on the Georges River Flood Study (BMT, 2020). These adopted values appear reasonable and based on the best available data.

As noted in the Hydrology and Flooding Assessment (sections 4 to 7), although the proposal area is not coastal, sea level rise will still impact the average height and potential flood peak of the Georges River. However peak flood levels are upstream of the existing bridge which is not predicted to be submerged in flood events up to and including the Probable Maximum Flood event. In addition, no inundation of the existing M5 Motorway is predicted in a 1% AEP event.

River height and flood peaks have the potential to undermine slope stability, increase the frequency of inundation and prevent effective drainage during extreme rainfall events. The Hydrology and Flooding Assessment notes that the design is required to achieve immunity to a 1% AEP event. Slope stability was considered in the current 80% design, and all new or regraded slopes are recommended to be vegetated to control erosion.

Increasing atmospheric carbon dioxide

Increased atmospheric CO_2 is driving climate change and is projected to continue with very high confidence (Dowdy et al., 2015). The expected increase in atmospheric CO_2 concentrations under the RCP8.5 scenario is shown in Figure 8, along with the expected increase in global average surface temperatures.

This increase in atmospheric CO_2, along with associated increases in temperature and humidity, has the potential to impact the durability of concrete in longer-lived structural assets. Current construction standards do not account for the likely increased rate of carbonation of concrete under climate change. Under RCP8.5, carbonation is likely to reduce the structural durability of concrete and subsequently impact the service life of assets.

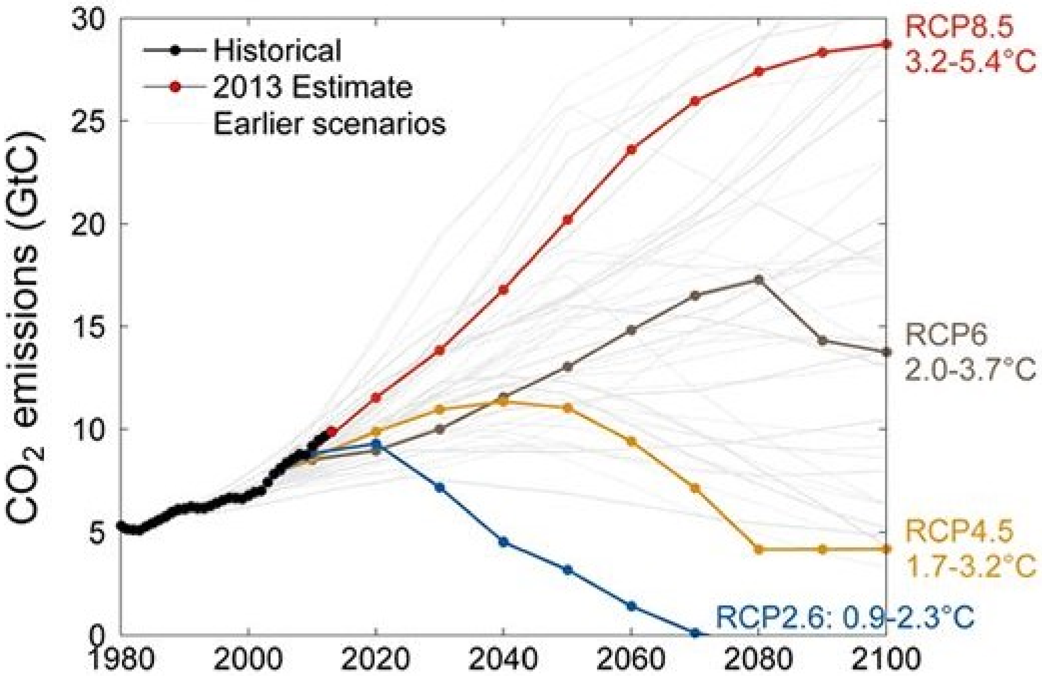

Figure 8 Observed emissions and future projections (Global Carbon Project)

4 Risk assessment

A climate risk assessment was carried out to identify climate risks and subsequent risk ratings relevant to the proposal.

4.1 Scope and definition

The scope of the assessment includes all asset types covered by the proposal (road pavements, road surfacing layers, drainage, roadsides, structures, ITS/electrical assets) and operations to build, maintain and operate these assets. Table 4 lists the type of assets being addressed by this contract along with the relevant subcategories.

Table 4 Asset type and subcategories

Asset type	Description	Subcategories	
Road pavements	Road pavement is the durable material laid down to carry and distribute the weight of the wheel loads of vehicular traffic without deforming and causing damage to the surface layers. Road pavement layers are made up of compacted layers of structural fill and crushed rock.	▪ Concrete, asphalt, spray seal, and unsealed roads ▪ Off-road paved area	▪ Non-asphalt paving ▪ Pavement repairs – major and minor ▪ Pavement condition ▪ ROCOND Maintenance Segment (ROCOND 90: Road Condition Manual)
Road surfacing layers	The purpose of the road surfacing is to provide a low maintenance all-weather riding surface, which protects the underlying structural road pavement from ingress of free water. Water weakens the unbound material, causing potholes, ruts and corrugations.	▪ Concrete, asphalt, spray seal, and unsealed roads ▪ Linear pavement markings	▪ Pavement condition ▪ Slope sight
Drainage	Drainage is essential for roads to ensure the shed of water off the pavement and to ensure safe travel for vehicles during rainfall events.	▪ Bridge size culvert ▪ Drainage (installation) ▪ Drain cleaning ▪ Culvert	▪ Kerb gutter ▪ Open drainage ▪ Stormwater quality improvement devices ▪ Sub-soil drainage
Roadsides	Roadsides provide areas for placement of signs and safety barriers, for landscaping and amenity, and bicycle paths, visual screening, as well as areas for the safe recovery of vehicles in emergency situations.	▪ Advanced warning signs ▪ Cycleways ▪ Land management ▪ Retro reflectivity ▪ Roadside landscaping	▪ Signs ▪ Soil nailing and shotcrete ▪ Stockpile site ▪ Tree removal
Structures	Includes bridges, large culverts, steel gantries and cantilever sign supports, retaining walls and noise barriers.	▪ Bridge bearing and expansion joint replacement ▪ Bridge repairs ▪ Bridge size culvert ▪ Fencing ▪ Median ▪ Noise wall	▪ Road furniture ▪ Safety barrier ▪ Safety ramps ▪ Slope and retaining walls ▪ Support structure ▪ Tunnel structure ▪ Tunnel works

Asset type	Description	Subcategories	
ITS/electrical assets	Includes traffic signals and on-road electrical devices such as illuminated or dynamic road signs, CCTV monitoring cameras, help phones and various vehicle detection and warning sings, and streetlights.	▪ CCTV camera ▪ Changeable message signs ▪ Electrical mechanical assets ▪ Emergency phone ▪ Enforcement system ▪ Over-height detection systems ▪ Over-speed detection systems ▪ Street lighting	▪ Tidal flow systems ▪ Traffic control system ▪ Traffic monitoring unit ▪ Travel Time Information System ▪ Variable message sign ▪ Variable speed limit signs ▪ Vehicle Detection Classification System ▪ Weight In Motion System
Operations	Construction and maintenance program to build, maintain, and operate roads.	▪ Operations and maintenance ▪ Graffiti removal	▪ Road sweeping

4.2 Risk identification

The range of possible ways that climate hazards might impact the proposal were assessed. To aid the identification of climate hazards climate change was divided into three hazard groups to capture the potential risks posed by these hazards:

- Bushfires
- Chronic heat
- Extreme heat events
- Extreme rainfall events
- Increased atmospheric CO_2
- Increased humidity.

A comprehensive range of risks were identified and are detailed as part of Table 5.

4.3 Risk evaluation

The business as usual (BAU) likelihood and consequence of the risks were assessed in accordance with the AS-5334 guidance and rated using an AS-5334 compliant rating table (Appendix A). For the purposes of this assessment, BAU was assessed as the current 80% design operating under the RCP8.5 climate scenario detailed in Section 3.2.2. The rated risks are detailed in Table 5.

Table 5 M5 Motorway Westbound Traffic Upgrade climate risks and risk ratings

Risk ID	Asset / Capability Type	Project phase	Hazard	Risk statement	Risk type	Asset life (years)	BAU likelihood	BAU consequence	BAU risk rating
1	Road pavements and surfacing layers, Structures, Operations, ITS/Electrical Assets	Operation	Bushfires	Bushfires cause road, bridge, and underpass closures and damage to assets	Direct	50-100	Rare	Moderate	Low
2	Staff	Construction and operation	Bushfires	Poor air quality and reduced visibility associated with bushfire smoke makes outdoor work unsafe, impacting crew health and safety	Direct	NA	Likely	Moderate	Moderate
3	Operations	Operation and maintenance	Bushfires	Poor air quality and reduced visibility associated with bushfire smoke results in delays repairing damage and maintaining assets	Direct	NA	Likely	Moderate	Moderate
4	Structures, Roadsides, Road pavements and surfacing layers	Operation	Chronic heat	More frequent exposure to high temperatures increases the rate at which metal assets rust and deteriorate, and the carbonation depth of concrete, reducing their structural durability and safe operational life	Direct	50-100	Possible	Moderate	Moderate
5	Structures, Roadsides, Road pavements and surfacing layers	Operation	Chronic heat	More frequent exposure to high temperatures increases the rate at which structures, pavements and road surfaces fatigue, reducing their durability and safe operational life	Direct	50-100	Possible	Moderate	Moderate
6	Staff	Construction and operation	Chronic heat	Increasingly frequent and severe high heat days lead to field crews experiencing health and safety incidents (heat exposure, dehydration, fatigue)	Direct	50-100	Rare	Moderate	Low
7	Social/cultural	Operation	Chronic heat	Urban heat island effects, severe heat days and increasingly frequent heat impact on users of the shared access path	Direct	50-100	Likely	Major	High
9	Vegetation & Landscaping	Operation and maintenance	Chronic heat	Increasingly frequent and severe heat days, and drought, damage vegetation and landscaping, and limit the possibility of establishing new vegetation	Direct	NA	Likely	Moderate	Moderate

Risk ID	Asset / Capability Type	Project phase	Hazard	Risk statement	Risk type	Asset life (years)	BAU likelihood	BAU consequence	BAU risk rating
10	Road Users	Operation and maintenance	Climate-related events	Road closures during climate-related extreme events prevent emergency services from responding to critical incidents, resulting in serious adverse human health effects (including incidents of total disability or fatality)	Direct	NA	Likely	Major	High
11	Structures	Operation	Drought	Shrinking and swelling of ground surfaces during increasingly frequent and severe drought and heavy rain cycles undermine the stability of structural supports	Direct	NA	Rare	Moderate	Low
12	ITS/Electrical Assets, Operations	Operation	Extreme heat events	Extreme heat events degrade electronic boards, overheat systems, cause controller failures and power outages and blackouts, resulting in network disruption	Indirect	20-30	Possible	Moderate	Moderate
13	Structures	Operation	Extreme heat events	Utilities (electricity and telecommunications) that cross the river on the underside of the bridge are disrupted by increasingly frequent and severe extreme heat events	Direct	NA	Rare	Moderate	Low
14	Structures, Roadsides, Road pavements and surfacing layers	Operation	Extreme heat events	Increasingly frequent and severe extreme heat events damage and fatigue pavements and road surfaces, reducing their durability and safe operational life	Direct	20-30	Possible	Moderate	Moderate
15	Road pavements and surfacing layers, Roadsides	Operation and maintenance	Extreme heat events	Increasingly frequent and severe extreme heat events cause line markings and static signs to fade before their anticipated renewal date	Direct	NA	Possible	Minor	Low
16	Roadsides	Operation	Extreme heat events	Increasingly frequent and severe extreme heat events cause road assets and furniture to warp, shortening their design and operational life	Direct	20-30	Possible	Minor	Low
17	Drainage, Structures, Operations	Construction and operation	Extreme rainfall events	Flooding and flash flooding due to extreme rainfall causes road, bridge and underpass closures	Direct	50-100	Likely	Major	High

Risk ID	Asset / Capability Type	Project phase	Hazard	Risk statement	Risk type	Asset life (years)	BAU likelihood	BAU consequence	BAU risk rating
18	Drainage, Structures, Operations	Operation	Extreme rainfall events	Flooding and flash flooding due to extreme rainfall damages road, bridge and underpass infrastructure, and reduces asset life	Direct	50-100	Unlikely	Major	Moderate
19	Drainage, Structures, Operations	Design and operation	Extreme rainfall events	Flooding and flash flooding due to extreme rainfall causes large debris to wash down the river, impacting bridge supports, though it is unlikely that the supports would be damaged	Direct	50-100	Unlikely	Minor	Low
20	Drainage, Structures, Operations, Road Users	Construction and operation	Extreme rainfall events	Unsafe conditions due to extreme rainfall cause road, bridge, and underpass closures	Direct	50-100	Likely	Major	High
21	Drainage, Structures, Operations, Road Users	Construction and operation	Extreme rainfall events	Unsafe conditions due to extreme rainfall cause traffic accidents	Direct	50-100	Likely	Major	High
22	Drainage, Structures, Operations, Road Users	Construction and operation	Extreme rainfall events	Windblown debris and/or hail during extreme storm events cause road, bridge, and underpass closures	Direct	50-100	Likely	Moderate	Moderate
23	Drainage, Structures, Operations, Road Users	Operation	Extreme rainfall events	Windblown debris and/or hail during extreme storm events cause road accidents	Direct	50-100	Likely	Moderate	Moderate
24	Drainage, Structures, Operations	Operation	Extreme rainfall events	Lightning strikes during extreme storms disrupt electrical and ITS systems, causing traffic disruption	Direct	50-100	Possible	Moderate	Moderate
25	Structures	Operation	Extreme rainfall events	Extreme rainfall causes slope failures and landslips that damage roads and bridge support structures	Direct	50-100	Possible	Major	High
26	Structures	Operation	Extreme rainfall events	Utilities (electricity and telecommunications) that cross the river on the underside of the bridge are disrupted by flooding associated with increasingly frequent and severe extreme rainfall events	Direct	50-100	Likely	Moderate	Moderate
28	Waterways	Construction and maintenance	Extreme rainfall events	Extreme rainfall events, particularly after extended dry spells, wash contaminants from work sites into waterways	Indirect	NA	Possible	Moderate	Moderate

Risk ID	Asset / Capability Type	Project phase	Hazard	Risk statement	Risk type	Asset life (years)	BAU likelihood	BAU consequence	BAU risk rating
29	ITS/Electrical Assets, Operations	Operation	Extreme rainfall events	Power outages caused by severe storms impact ITS, resulting in intersection blackouts, network disruption and traffic jams	Indirect	20-30	Possible	Moderate	Moderate
30	ITS/Electrical Assets	Operation	Extreme rainfall events	Water ingress during extreme rainfall events damage ITS and electronic components, causing network disruption	Direct	20-30	Possible	Moderate	Moderate
31	Road pavements and surfacing layers	Design and operation	Extreme rainfall events	Increasingly frequent and severe rainfall events undermine subsurface soil layers, causing land instability and sink holes	Direct	20-30	Possible	Moderate	Moderate
32	Drainage, Road pavements and surfacing layers, Operations, ITS/Electrical Assets	Design and operation	Extreme rainfall events	Increasingly frequent and severe rainfall events exceed the carrying capacity of existing drainage system, causing ponding, flooding and flash flooding that damages assets and closes roads	Direct	50-100	Likely	Major	High
33	Drainage, Waterways, Road pavements and surfacing layers, Operations, ITS/Electrical Assets	Design and operation	Extreme rainfall events	Receiving wetlands and waterways become inundated during extreme rainfall events and stops draining effectively, causing upstream ponding, flooding and flash flooding.	Indirect	50-100	Likely	Major	High
34	Drainage, Road pavements and surfacing layers, Structures, Operations, ITS/Electrical Assets, Road Users	Design and operation	Extreme rainfall events	Increasingly frequent and severe rainfall events exceed the carrying capacity of drainage systems, causing flooding and slope failures that damage assets	Direct	50-100	Likely	Major	High
35	Road pavements and surfacing layers, Drainage	Design and operation	Extreme rainfall events	Increasingly frequent and extreme rainfall events cause potholes that damage vehicles	Direct	20-30	Likely	Moderate	Moderate
36	Property, Drainage, Road Users	Design an operation	Extreme rainfall events	Increased overland flow exceeds the capacity of drainage systems and causes damage to public and private property	Direct	50-100	Likely	Moderate	Moderate
37	Vegetation & Landscaping	Maintenance	Extreme rainfall events	Increasingly frequent and severe extreme rainfall events damage remnant vegetation and landscaping	Direct	NA	Likely	Moderate	Moderate

Risk ID	Asset / Capability Type	Project phase	Hazard	Risk statement	Risk type	Asset life (years)	BAU likelihood	BAU consequence	BAU risk rating
38	Roadsides, Operations, ITS/Electrical Assets	Operation and maintenance	Extreme rainfall events	Increasingly frequent and severe rainfall events transport excessive vegetation and debris onto roads, causing road closures and network disruptions	Direct	50-100	Likely	Moderate	Moderate
39	Drainage, Roadsides	Operation and maintenance	Extreme rainfall events	Increasingly frequent and severe rainfall events cause excessive vegetation and debris to block drainage systems, causing flooding, flash flooding and slope failures that result in road closures and asset damage	Direct	50-100	Possible	Major	High
40	Structures, Roadsides	Operation and maintenance	Increased atmospheric CO_2	More frequent exposure to acid rain increases the rate at which metal assets rust and deteriorate, and increases the carbonation depth of concrete assets, reducing their structural durability and safe operational life	Direct	50-100	Possible	Moderate	Moderate
41	Structures, Roadsides	Operation and maintenance	Increased humidity	More frequent exposure to high relative humidity increases the rate at which metal assets rust and deteriorate, and increases the carbonation depth of concrete assets, reducing their structural durability and safe operational life	Direct	50-100	Possible	Moderate	Moderate

5 Adaptation options

This initial risk assessment considers climate risk sufficiently for the purposes of the REF. Ideally, the highest rated risks identified in this report would be further assessed and mitigation options integrated into the final design of the proposal.

The extremely localised scope of this climate risk assessment, focused on the proposal, resulted in no extreme and very few high risks being identified. These high risks are based on BAU action under the RCP8.5 climate scenario. With mitigation measures and adaptation action, the residual risk rating for these risks is likely to reduce to moderate.

5.1 Existing adaptation measures

The high risks primarily relate to extreme rainfall events and associated storm surge and flooding impacts; however, adaptation to mitigate these risks has already been carried out through the inclusion of the impact of climate change in the Hydrology and Flooding Assessment (Aurecon, 2022), and the Surface Water and Groundwater Technical Assessment (Aurecon, 2022). Implementation of the report recommendations into the final design of the proposal would reduce the residual risk associated with extreme rainfall to moderate.

Other high risks identified in the risk assessment are associated with the predicated increase in extreme heat events. Some of these may be reduced through changes to the final design, such as providing shade for the shared use access path. However, there is a limit to which these risks can be economically mitigated, given the strength of materials necessary for large transport infrastructure. It is therefore likely that the proposal would contribute to and be impacted by increasingly severe urban heat island effects.

5.2 Potential further risk mitigation

The risks associated with extreme rainfall events have potential to be further reduced through the inclusion of a design buffer beyond 1% annual exceedance probability (AEP) in the structures final design. This would also account for any under-estimation of flood and storm surge risk associated with the use of NARCliM data as the basis for the climate change aspects of the Surface Water and Groundwater Technical Assessment. NARCliM is an older dataset that yields rainfall estimates somewhat lower than more recent CSIRO and Bureau of Meteorology (BoM) climate projections. In addition, a higher AEP would allow a buffer for resilience, recognising that we do not understand the full extent of climate change impacts on natural systems.

5.3 Recommended further investigations

This assessment identified ‘high’ risks associated with extreme rainfall and heat. A more detailed climate risk assessment and climate adaptation plan would allow these risks to be more thoroughly interrogated. It is recommended that this assessment is supported by an evaluation to characterise the likely impacts for ‘high’ risks (and potentially some ‘moderate’ risks where the consequence is ‘major’ or ‘moderate’).

Adaptation through increased drainage systems or alternate material selections to treat ‘high’ risks, as well as selected/material ‘moderate’ risks, should be evaluated for optimal scale and timing. For example, an adaptation may be triggered when a specific climate threshold is likely to be reached, or in line with maintenance schedules. This evaluation should also include a cost-benefit analysis that considers the optimal scale and timing of adaptations for inclusion in design and evaluated compared to the cost-benefit of adapting now and the cost-benefit of Doing Nothing. Where the optimal timing of an adaptation is in the future, there should be consideration of the future-proofing requirements in design.

A more detailed climate risk assessment in line with AS 5334 would also allow a broader exploration of climate risk. In particular, climate change impacts occur at both localised and regional levels. Though this risk assessment was limited to the site of the proposal, the operation of this infrastructure would be affected by regional and network-level climate impacts.

There is opportunity to broaden the risk assessment further to consider natural hazards and system shocks and stressors. Risks may warrant further investigation include:

- Identifying cascading and compound natural hazard risks, including those that flow from and through the broader road network
- Considering the impact of shocks and stressors on the proposal area.

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Appendix A: Risk assessment criteria

Table A1 Risk rating matrix adopted from AS 5334-2013

Likelihood	Consequences				
	Insignificant	**Minor**	**Moderate**	**Major**	**Catastrophic**
Almost Certain	Low	Moderate	High	Extreme	Extreme
Likely	Low	Moderate	Moderate	High	Extreme
Possible	Low	Low	Moderate	High	Extreme
Unlikely	Low	Low	Moderate	Moderate	High
Rare	Low	Low	Low	Moderate	Moderate

TABLE B1

RISK CRITERIA—EXAMPLE OF QUALITATIVE MEASURES OF CONSEQUENCES

Consequence descriptor	Adaptive capacity (see Note 1)	Infrastructure, service	Social/cultural	Governance	Financial (see Note 2)	Environmental (see Note 3)	Economy (see Note 4)
Insignificant	No change to the adaptive capacity	No infrastructure damage, little change to service	No adverse human health effects	No changes to management required	Little financial loss or increase in operating expenses	No adverse effects on natural environment	No effects on the broader economy
Minor	Minor decrease to the adaptive capacity of the asset. Capacity easily restored	Localized infrastructure service disruption No permanent damage. Some minor restoration work required Early renewal of infrastructure by 10–20% Need for new/modified ancillary equipment	Short-term disruption to employees, customers or neighbours Slight adverse human health effects or general amenity issues	General concern raised by regulators requiring response action	Additional operational costs Financial loss small, <10%	Minimal effects on the natural environment	Minor effect on the broader economy due to disruption of service provided by the asset
Moderate	Some change in adaptive capacity. Renewal or repair may need new design to improve adaptive capacity	Limited infrastructure damage and loss of service Damage recoverable by maintenance and minor repair Early renewal of infrastructure by 20–50%	Frequent disruptions to employees, customers or neighbours. Adverse human health effects	Investigation by regulators Changes to management actions required	Moderate financial loss 10–50%	Some damage to the environment, including local ecosystems. Some remedial action may be required	High impact on the local economy, with some effect on the wider economy
Major	Major loss in adaptive capacity. Renewal or repair would need new design to improve adaptive capacity	Extensive infrastructure damage requiring major repair Major loss of infrastructure service Early renewal of infrastructure by 50–90%	Permanent physical injuries and fatalities may occur Severe disruptions to employees, customers or neighbours	Notices issued by regulators for corrective actions Changes required in management. Senior management responsibility questionable	Major financial loss 50–90%	Significant effect on the environment and local ecosystems. Remedial action likely to be required	Serious effect on the local economy spreading to the wider economy
Catastrophic	Capacity destroyed, redesign required when repairing or renewing asset	Significant permanent damage and/or complete loss of the infrastructure and the infrastructure service Loss of infrastructure support and translocation of service to other sites Early renewal of infrastructure by >90%	Severe adverse human health effects, leading to multiple events of total disability or fatalities Total disruptions to employees, customers or neighbours Emergency response at a major level	Major policy shifts Change to legislative requirements Full change of management control	Extreme financial loss >90%	Very significant loss to the environment. May include localized loss of species, habitats or ecosystems Extensive remedial action essential to prevent further degradation. Restoration likely to be required	Major effect on the local, regional and state economies

(*continued*)

Figure A1 Consequence rating guidance (AS 5334-2013)

TABLE C1

EXAMPLE OF QUALITATIVE MEASURES OF LIKELIHOOD

Rating	Descriptor	Recurrent or event risks	Long term risks
Almost certain	Could occur several times per year	Has happened several times in the past year and in each of the previous 5 years *or* Could occur several times per year	Has a greater than 90% chance of occurring in the identified time period if the risk is not mitigated
Likely	May arise about once per year	Has happened at least once in the past year and in each of the previous 5 years *or* May arise about once per year	Has a 60–90% chance of occurring in the identified time period if the risk is not mitigated
Possible	Maybe a couple of times in a generation	Has happened during the past 5 years but not in every year *or* May arise once in 25 years	Has a 40–60% chance of occurring in the identified time period if the risk is not mitigated
Unlikely	Maybe once in a generation	May have occurred once in the last 5 years *or* May arise once in 25 to 50 years	Has a 10–30% chance of occurring in the future if the risk is not mitigated
Rare	Maybe once in a lifetime	Has not occurred in the past 5 years *or* Unlikely during the next 50 years	May occur in exceptional circumstances, i.e. less than 10% chance of occurring in the identified time period if the risk is not mitigated

Figure A2 Likelihood rating guidance (AS 5334-2013)

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