Appendix X

Climate change risk assessment framework

WestConnex

Roads and Maritime Services

M4-M5 Link

Environmental Impact Statement

Climate change risk assessment framework

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Client: Roads and Maritime Services

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Glossary of terms and abbreviations

Term	Meaning
Adaptation	The process of adjustment to actual or expected climate and its effects. Adaptation can be autonomous or planned (CSIRO and BoM 2015a).
ARI	Average recurrence interval. An indicator used to describe the frequency of floods. The average period in years between the occurrence of a flood of a particular magnitude or greater. In a long period of say 1,000 years, a flood equivalent to or greater than a 100 year ARI event would occur 10 times. The 100 year ARI flood has a one per cent chance (i.e. a one-in-100 chance) of occurrence in any one year. Floods generated by runoff from the study catchments are referred to in terms of their ARI, for example the 100 year ARI flood.
AR5	IPCC Fifth Assessment Report
BoM	Bureau of Meteorology
Bushfire	Bushfires in Australia occur as grass fires or forest fires.
Climate change	A change in the state of the climate that can be identified (eg by statistical tests) by changes in the mean and/or variability of its properties, and that persists for an extended period of time, typically decades or longer (CSIRO and BoM 2015a).
Climate projection	A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/radiative forcing scenario used, which in turn is based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realised (CSIRO and BoM 2015a).
CO_2	Carbon dioxide. A naturally occurring gas, also a by-product of burning fossil fuels from fossil carbon deposits, such as oil, gas and coal, of burning biomass, of land use changes and of industrial processes (eg cement production). It is the principle anthropogenic greenhouse gas that affects the Earth's radiative balance (CSIRO and BoM 2015a).
CSIRO	Commonwealth Scientific and Industrial Research Organisation.
Emissions scenario	A plausible representation of the future development of emissions of substances that are potentially radiatively active (eg greenhouse gases, aerosols) based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socioeconomic development, technological change) and their key relationships (CSIRO and BoM 2015a).
ENSO	El Niño–Southern Oscillation. A fluctuation in global scale tropical and subtropical surface pressure, wind, sea surface temperature and rainfall, and an exchange of air between the southeast Pacific subtropical high and the Indonesian equatorial low (CSIRO and BoM 2015a).
Extreme temperature	Definitions vary; however, this document uses 'extreme temperature' to denote days above 35˚C.
Extreme rainfall	There is no consistent global definition for extreme rainfall. It can be defined by either relative rainfall at a location (amount relative to averages), or absolute rainfall amounts (eg over 100 millimetres in a single day). In this document, an extreme rainfall event is defined as the wettest day in 20 years.
FFDI	Forest fire danger index.
Fire weather	Weather conditions conducive to triggering and sustaining wild fires, usually based on a set of indicators and combinations of indicators including temperature, soil moisture, humidity, and wind. Fire weather does not include the presence or absence of fuel load (CSIRO and BoM 2015a).

Term	Meaning
Greenhouse gas	Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere (CSIRO and BoM 2015a).
IOD	Indian Ocean Dipole. Large-scale mode of interannual variability of sea surface temperature in the Indian Ocean. This pattern manifests through a zonal gradient of tropical sea surface temperature, which in its positive phase from September to November shows cooling off Sumatra and warming off Somalia in the west, combined with anomalous easterlies along the equator (CSIRO and BoM 2015a).
IPCC	Intergovernmental Panel on Climate Change
Mean rainfall	The arithmetically averaged total precipitation recorded during a calendar month or year (BoM 2007).
NARCliM	NSW/ACT Regional Climate Modelling
O/C	Overall construction cost
PMF	Probable Maximum Flood. The flood that occur as a result of the probable maximum precipitation on a study catchment. The probable maximum flood is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The probable maximum flood defines the extent of flood prone land (ie the floodplain).
RCP	Representative concentration pathways. Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases and aerosols and chemically active gases, as well as land use/cover (CSIRO and BoM 2015a).
Roads and Maritime	NSW Roads and Maritime Services
WCL	Workers compensation liability

1 Risk assessment framework

Table 1-1 and **Table 1-2** provide the likelihood and consequence criteria used for the climate change risk assessment. The criteria are from the *Guidelines for Risk Management* (NSW Roads and Maritime Services (Roads and Maritime) 2014).

Table 1-1 Likelihood criteria

Likelihood rating	Description		Probability parameters	
Extreme	Almost certain	The event is expected to occur in most circumstances	>90% probability	>1 in one year
High	Likely	The event will probably occur in most circumstances	51% to 90% probability	1 in 10 years
Medium	Moderate	The event should occur at some time	21% to 50% probability	1 in 50 years
Low	Unlikely	The event could occur at some time	10% to 20%	1 in 100 years
Negligible	Rare	The event might occur in exceptional circumstances	<10% probability	1 in 1000 years

Source: Guidelines for Risk Management (Roads and Maritime 2014)

Table 1-2 Consequence criteria – impacts on the project objectives (Roads and Maritime Guidelines for Risk Management)

Consequence rating	Time: Development	Time: Delivery	Cost: Development	Cost: Delivery	Safety: Delivery	Safety: Operation	Environment Delivery Operation	Traffic flow peak hour	Local traffic	Community attitude	Fit for purpose Defects Accidents Maintenance costs
Extreme	Year	Months	$(25% overall construction cost)	$(10% overall construction cost)	Worker's Compensation Liability > $250,000 Death, permanent loss of physical or mental amenity	Multiple Worker's Compensation Liability > $250,000 Death, permanent loss of physical or mental amenity	Major environmental damage and/or delay due to legal finding in Land and Environment Court	No improvement	Severe disruption	Severe community protests	Functional failure
High	Months	Months	$(15% overall construction cost)	$(7% overall construction cost)	Worker's Compensation Liability $10,001 – $250,000 Lost time >= 5 days	Worker's Compensation Liability >$250,000 Death, permanent loss of physical or mental amenity	Serious environmental damage and/or delay due to public inquiry or NSW Environment Protection Authority (EPA) major notice	Marginal improvement	Disruption	Community protests	Serious functional failure

Consequence rating	Time: Development	Time: Delivery	Cost: Development	Cost: Delivery	Safety: Delivery	Safety: Operation	Environment Delivery Operation	Traffic flow peak hour	Local traffic	Community attitude	Fit for purpose Defects Accidents Maintenance costs
Medium	Months	Months	$(7.5% overall construction cost)	$(4% overall construction cost)	Worker's Compensation Liability $1,001 – $10,000 Lost time 1-4 days	Worker's Compensation Liability $10,001-$250,000 Lost time >= 5 days	Environmental damage and/or EPA infringement notice			Daily complaints	Minor functional failure
Low	Months	Weeks	$(1% overall construction cost)	$(1% overall construction cost)	Worker's Compensation Liability $251 – $1000 Lost time >= 1 day	Worker's Compensation Liability $1001 – $10,000 Lost time 1-4 days	Minor environmental damage and/or minor EPA infringement notices, written community complaints	km/hr		Complaints	
Negligible	Weeks	Nil	$(0.1% overall construction cost)	$(0.1% overall construction cost)	Worker's Compensation Liability $1 – $250 First aid treatment (no lost time)	Worker's Compensation Liability $252 – $1000 Lost time >= 1 day	Minor repairable environmental damage Verbal community comment	km/hr		Negligible complaints	

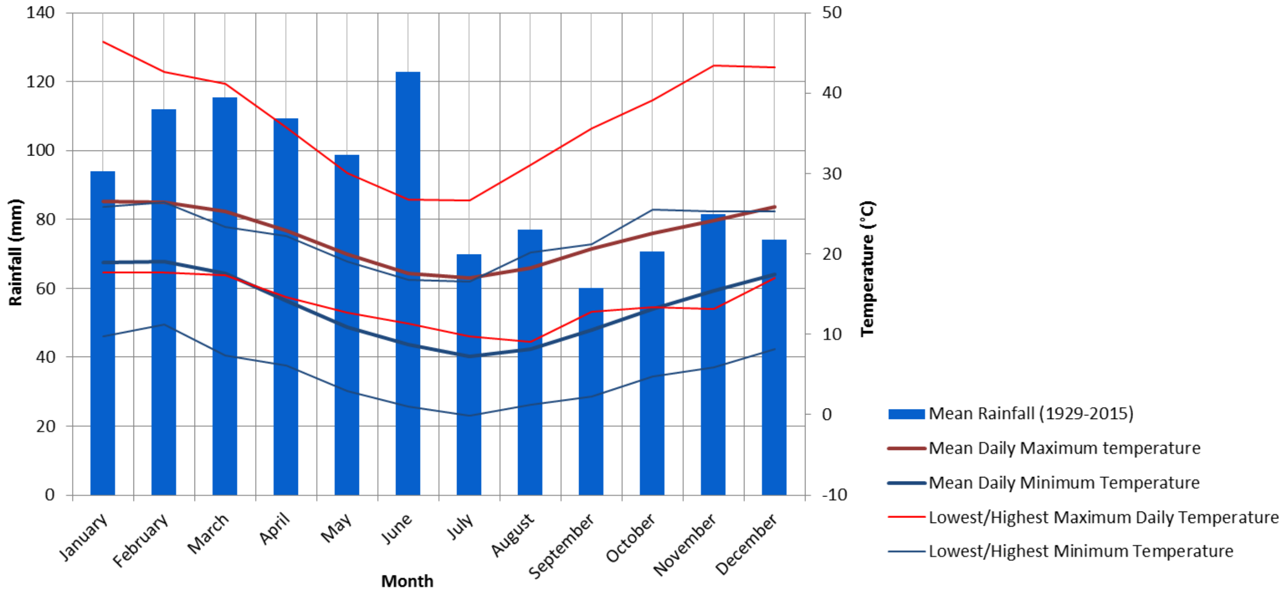
Source: Guidelines for Risk Management (Roads and Maritime Services 2014)

2 Existing and historical climate

2.1 Existing climate

Figure 2-1 shows the climate profile for the project region, indicated by weather monitoring data obtained from the Sydney Airport AMO Bureau of Meteorology (BoM) Monitoring Station for the period 1939 to 2015 (1929 to 2015 for rainfall data). Climate data from the Sydney Airport monitoring station is representative of conditions across the project corridor, as it is located around three kilometres from the eastern end of the project, within a similar physical environment (built up, coastal and low elevation).

Figure 2-1 indicates that the wettest month in the project region is June, followed by February and March. The driest month is September. Generally, January through to June has more rainfall than the second half of the year. Historical rainfall records between 1929 and 2015 show an annual mean rainfall of 1085.3 millimetres. Mean maximum daily temperatures range between 17°C and 18.3°C in winter, and between 25.8°C and 26.4°C in summer.



Source: Sydney Airport AMO BoM Monitoring Station

Figure 2-1 Climate profile for Sydney

2.2 Historical trends

2.2.1 Mean surface temperature

Surface air temperatures have been increasing along the east coast of Australia since national records began in 1910, and in particular, since 1960 (Commonwealth Scientific and Industrial Research Organisation (CSIRO) and BoM 2015). Mean surface temperature along the east coast of Australia has increased by about 0.8˚C since 1910 (CSIRO and BoM 2015).

2.2.2 Extreme heat

Historical observations show that mean temperature changes in Australia have been accompanied by large increases in extreme temperatures (CSIRO and BoM 2015). There has been a recent significant increase in the frequency of high temperature extremes and heatwave events, and a decline in the frequency of low temperature extremes (CSIRO and BoM 2015). The number of very warm months has increased five-fold in the past 15 years, and the number of very cool months has declined by around a third (CSIRO and BoM 2015).

2.2.3 Mean annual rainfall

Rainfall in Australia is highly variable, spatially and temporally, and is influenced by a number of key local processes such as the El Niño–Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD). As a result of the high rainfall variability in Australia, attributing observed rainfall changes to climate change is difficult. With the exception of the summer months, observations indicate declines in average rainfall of 10 to 20 per cent in south-eastern Australia over the cooler months (April to September), with some areas experiencing declines throughout the whole century (CSIRO and BoM 2015). Although there remains uncertainty regarding the cause, this decline has been linked to changes in the frequency and impact of ENSO and IOD, which are influenced by increasing greenhouse gases and reductions in ozone (CSIRO and BoM 2015).

2.2.4 Extreme rainfall

In Australia, extreme rainfall is driven by ENSO, east coast low pressure systems, tropical cyclones, monsoon troughs, severe thunderstorms, cut-off lows and mid-latitude fronts (CSIRO and BoM 2011; King et al. 2013). Historical rainfall observations show that the percentage of Australia's area receiving a greater than the 90th percentile of annual rainfall from heavy rainfall events has been increasing since the 1970s (CSIRO and BoM, 2015). However, there is large regional variability, with the east coast region experiencing a significant reduction in extreme rain events (CSIRO and BoM 2015).

2.2.5 Fire weather

In most Australian states, forest fire (or bushfire) weather risk is quantified using the McArthur Forest Fire Danger Index (FFDI) (Luke & McArthur 1978). FFDI is calculated using observed and modelled data on air temperature, relative humidity and wind speed in combination with an estimate of fuel levels. The FFDI incorporates fuel state through the 'drought factor', which depends on daily rainfall and time since the last rain, with an aim to account for long-term and short-term rainfall and its impact on fuel moisture.

FFDI values are classified into one of six fire danger ratings, ranging from low to catastrophic. These categories and their associated FFDI values are shown in **Table 2-1**.

Table 2-1 Forest fire danger index rating categories

Fire danger rating category	Forest fire danger index (FFDI)
Catastrophic	100+
Extreme	75–99
Severe	50–74
Very high	25–49
High	12–24
Low to moderate	0–11

Due to the strong relationship between bushfire risk and the weather, climate change will have a significant impact on future fire weather (CSIRO and BOM 2015). Past observations show an increase in annual cumulative FFDI across Australia over the period 1973 to 2010. The trend is particularly evident in south-eastern Australia, where the fire season has extended further into spring and autumn. Across Australia, including at the Sydney Airport and Richmond BoM stations, there has also been an increase in higher FFDI values, indicating that extreme fire weather days have become more frequent over time.

2.2.6 Sea level

The sea level at any point in time is the consequence of the mean sea level, the state of the tides, wave set up, responses to air pressure and local and remote near-shore winds, and may sometimes be affected by additional flows of water from on shore (NSW Department of Environment Climate Change and Water (DECCW) 2009).

Over the period of 1966 to 2009, relative sea level has risen around Australia at an average rate of 1.6 millimetres per year, when the influence of ENSO on sea level is removed (CSIRO and BoM 2015). Extreme sea levels are caused by a combination of factors including storm surges, wind, waves and astronomical tides. Along the NSW coastline, the majority of storm surges are caused by east coast low weather patterns (CSIRO and BOM 2015). Rising sea levels exacerbate extreme sea levels.

3 Screening

Table 3-1 provides the risk screening matrix developed for the project. On one axis are the key project components; the other axis presents the key climate variables relevant to the project. Where there is a relationship between a climate variable and a project element, this has been indicated in the matrix with an '✓'. Identified relationships form the basis of the development of risk scenarios in the following section, noting that one relationship might result in multiple risks, and multiple relationships may combine to result in a single risk.

Table 3-1 Risk screening matrix

		Project components											
		Tunnel drainage	Elevated/bridge structures	Surface road upgrades	Surface drainage	Water treatment facilities	Cuttings, embankments and retaining walls	Pavement and base layers	Ancillary infrastructure (signs, traffic signals, buildings, etc)	Power supply	Tunnel ventilation (including ventilation outlet)	Landscaping	M4-M5 Link road users
Climate variable	Extreme rainfall	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓
	Mean rainfall										✓	✓	
	Extreme temperature		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
	Mean surface temperature										✓	✓	
	Mean annual wind speed		✓						✓		✓		
	Atmospheric carbon dioxide (CO_2)	✓	✓	✓	✓		✓		✓				
	Bushfire weather									✓	✓		✓
	Sea level rise			✓	✓	✓	✓		✓	✓		✓	
	Extreme sea level			✓	✓		✓		✓	✓		✓	

4 Detailed risk assessment

The following tables provide the risk scenarios identified for the project, along with their likelihood and consequence ratings and subsequent risk levels. **Table 4-1** identifies risks for 2030 up to 2090 under RCP8.5 (high emissions).

Table 4-1 Detailed risk assessment for 2090 under a high scenario (RCP8.5)

Risk scenario	Likelihood	Consequence	Risk level
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.	High • Extreme rainfall is projected to increase by between five per cent and 40 per cent by 2090. While there is substantial uncertainty around the direction of change of mean rainfall, projections show an increase in the frequency and intensity of extreme rainfall events • Rozelle Bay is tidal and thus influenced by an increase in sea level. Sea level is projected to rise by around 0.88 metres by 2090.	High • Existing flooding along The Crescent and City West Link will be exacerbated by future climate change, which may result in road closure and network issues and potentially affect the safety of road users • Risk of significant loss and damages as the project in this location is anticipated to be located under the existing sea level.	Extreme
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, Iron Cove Creek and Cooks River.	Medium • Extreme rainfall is projected to increase by between five per cent and 40 per cent by 2090. While there is substantial uncertainty around the direction of change of mean rainfall, projections show an increase in the frequency and intensity of extreme rainfall events • The waterways throughout the project are tidal and thus influenced by an increase in sea level. Sea level is projected to rise by around 0.88 metres by 2090.	Medium • Localised flooding could lead to temporary road closure and some adverse effects on road users. The risk of loss and damages remains low in these areas however due to the low water levels associated with localised flooding.	Medium

Risk scenario	Likelihood	Consequence	Risk level
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.	Medium • Extreme rainfall is projected to increase by between five per cent and 40 per cent by 2090. While there is substantial uncertainty around the direction of change of mean rainfall, projections show an increase in the frequency and intensity of extreme rainfall events • The waterways throughout the project are tidal and thus influenced by an increase in sea level. Sea level is projected to rise by around 0.88 metres by 2090 • The Rozelle Rail Yards are generally a low flood hazard area and not subject to flooding from Whites Creek as the Inner West Light Rail line and City West Link provide physical barriers to flow; however, during the probable flood maximum (PMF) Whites Creek overtops the road at The Crescent and flows in an easterly direction along City West Link, merging floodwaters from Rozelle Rail Yards and Whites Creek.	High • Localised basin in Rozelle currently subject to localised flooding • Existing drainage infrastructure does not have capacity to handle current PMF conditions, failure leads to flooding.	High

Risk scenario	Likelihood	Consequence	Risk level
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 • Extreme rainfall is projected to increase by between five per cent and 40 per cent by 2090. While there is substantial uncertainty around the direction of change of mean rainfall, projections show an increase in the frequency and intensity of extreme rainfall events • Existing overland flow paths along Victoria Road within the Iron Cove catchment are predominantly medium flood hazard, but there are localised areas of high flood hazard on the northern carriageway of Victoria Road for the 100 year average recurrence interval (ARI).	Medium • Localised flooding would reduce capacity of roadway • Localised flooding could impact road users • Localised flooding leading to damage to substations and power outages.	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, and landscaped areas and through tunnel outlets.	Medium • Extreme rainfall is projected to increase by between five per cent and 40 per cent by 2090. While there is substantial uncertainty around the direction of change of mean rainfall, projections show an increase in the frequency and intensity of extreme rainfall events.	Medium • Localised flooding would reduce capacity of roadway • Localised flooding could impact road users • Localised flooding leading to damage to substations and power outages.	Medium

Risk scenario	Likelihood	Consequence	Risk level
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 for the Rozelle Rail Yards and the proposed bioretention facility associated with the Iron Cove Link surface works, located within King George Park, adjacent to Manning Street at Rozelle.	Medium • Extreme rainfall is projected to increase by between five per cent and 40 per cent by 2090. While there is substantial uncertainty around the direction of change of mean rainfall, projections show an increase in the frequency and intensity of extreme rainfall events • The waterways throughout the project are tidal and thus influenced by an increase in sea level. Sea level is projected to rise by around 0.88 metres by 2090.	Medium • Increased saltwater intrusion may prevent wetlands from properly performing, with increased salinity resulting in a loss of freshwater dependant vegetation within the wetlands, and leading to a potential uncontrolled release of stormwater and increased risk of localised flooding.	Medium
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 • Extreme rainfall is projected to increase by between five per cent and 40 per cent by 2090. While there is substantial uncertainty around the direction of change of mean rainfall, projections show an increase in the frequency and intensity of extreme rainfall events • Decrease in mean rainfall and increase in evaporation (due to increased mean surface temperature) may change the likelihood of flooding during dry periods due to impacts on infiltration and groundwater recharge rates. It is expected that the event could occur at some time.	Medium • Localised flooding could adversely affect the safety of tunnel users, and operational personnel. The risk of significant loss and damages remains low due to low water levels associated with localised flooding • Localised flooding could lead to damage to substations and power outages • Localised flooding could lead to damage and functional failure of ancillary infrastructure • Localised flooding could lead to temporary tunnel closure which could in turn have some adverse impacts on the road network level of service.	Medium

Risk scenario	Likelihood	Consequence	Risk level
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 in Alexandra Canal and Hawthorne Canal and deterioration from saline intrusion.	Medium • The waterways throughout the project are tidal and thus influenced by an increase in sea level. Sea level is projected to rise by around 0.88 metres by 2090.	Medium • Saline intrusion would result in the accelerated deterioration of stormwater removal systems • Accelerated deterioration would result in additional operation and maintenance costs due to the retrofit works needed.	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 in Rozelle Bay and deterioration from saline intrusion.	Medium • Sea level is projected to rise by around 0.88 metres by 2090.	Medium • Reduced performance of water treatment system may result in the requirement for retrofitting works to the water treatment discharge infrastructure.	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 flooding of landscaped areas, particularly around the Rozelle interchange surface connections and the St Peters interchange.	Medium • Extreme rainfall is projected to increase by between 5 per cent and 40 per cent by 2090. While there is substantial uncertainty around the direction of change of mean rainfall, projections show an increase in the frequency and intensity of extreme rainfall events • The waterways throughout the project are tidal and thus influenced by an increase in sea level. Sea level is projected to rise by around 0.88 metres by 2090.	Low • Landscaped areas damaged from flooding may result in reduced visual amenity, as well as reduced habitat value and ecosystem function. This could adversely impact flora and fauna. Damaged landscaped areas may result in increased costs for rehabilitation and maintenance.	Low

Risk scenario	Likelihood	Consequence	Risk level
Increase in the intensity and frequency of extreme rainfall, combined with sea level rise leads to exacerbated risk on bicycle and pedestrian facilities such as the Bay Run connection at Iron Cove Bridge, connections at City West Link/The Crescent/Victoria Road/Anzac Bridge at Rozelle and at other surface portal locations (ie Wattle Street).	Medium • Extreme rainfall is projected to increase by between five per cent and 40 per cent by 2090. While there is substantial uncertainty around the direction of change of mean rainfall, projections show an increase in the frequency and intensity of extreme rainfall events • The waterways throughout the project are tidal and thus influenced by an increase in sea level. Sea level is projected to rise by around 0.88 metres by 2090.	Medium • Pedestrian and bicycle facilities inundated from flooding would result in disruptions to users as well as prevent mobility during hazardous events. Damaged infrastructure may result in increased costs for rehabilitation and maintenance.	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 slope instability or landslips at surface works.	Low • Extreme rainfall is projected to increase by between five per cent and 40 per cent by 2090. While there is substantial uncertainty around the direction of change of mean rainfall, projections show an increase in the frequency and intensity of extreme rainfall events • Risk of slope instability during extreme rainfall events may be exacerbated by a decrease in mean rainfall, and increase in evaporation (due to increase in mean temperature) • Cuttings and embankments are minimal.	Low • Subsidence or a landslip could result in minor volumes of material movement and may cause minor damage to pavement, localised sedimentation of the roadway, and associated minor safety hazards to users of the roadway.	Negligible

Risk scenario	Likelihood	Consequence	Risk level
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 events causing power outages (including subsequent pumping station failure) due to increased flooding.	Medium • Extreme rainfall is projected to increase by between five per cent and 40 per cent by 2090. While there is substantial uncertainty around the direction of change of mean rainfall, projections show an increase in the frequency and intensity of extreme rainfall events • Sea level is projected to rise by around 0.88 metres by 2090.	Medium • Power outage could result in traffic delays or reduced safety for road users and operational personnel due to functional failure of powered infrastructure.	Medium
Increase in the intensity and frequency of extreme rainfall and exacerbated risk of failure of the water treatment facility due to water inflow exceeding capacity of treatment facility at Rozelle Bay.	Medium • Extreme rainfall is projected to increase by between five per cent and 40 per cent by 2090. While there is substantial uncertainty around the direction of change of mean rainfall, projections show an increase in the frequency and intensity of extreme rainfall events • Decrease in mean rainfall and increase in evaporation (due to increased mean surface temperature) may reduce the likelihood of high inflows to the water treatment system during dry periods • The design of the water treatment plant incorporates contingency for high inflows of water, whereby high inflows from the western section of the project (towards Rozelle Bay) can overflow from the first holding tank into the deluge holding tank and then be discharged straight into Rozelle Bay.	Low • The contingency for high flows incorporated into the design of the water treatment plant would mitigate flooding of the water treatment system and drainage system. However, there may be downstream water quality impacts when untreated water is discharged directly into Rozelle Bay.	Low

Risk scenario	Likelihood	Consequence	Risk level
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.	Low • Road incidents as a result of extreme rainfall events already occur across the road network. The contribution of the projected changes in extreme rainfall to the risk of road incidents is expected to be minor.	High • A road incident could lead to injury or fatality of road users • A road incident could lead to temporary road closure which could in turn have significant adverse impacts on the road network level of service.	Medium
Mean rainfall and mean temperature			
Decrease in mean rainfall and increase in mean surface temperature and the intensity and frequency of extreme heat events adversely impacts landscaped areas.	Low • While there is substantial uncertainty around the direction of change of mean rainfall, some models show a decrease in mean rainfall of at least 15 per cent by 2090 • Mean surface temperature is projected to increase by up to 4.7°C by 2090 • The number of days above 35°C and 40°C are projected to increase by an average of 11 days and two days per year respectively, by 2090.	Low • Landscaped areas unable to adapt to changing climate may result in reduced visual amenity, as well as reduced habitat value and ecosystem function • Deteriorated landscaped areas may result in increased costs for rehabilitation and maintenance.	Negligible
Decrease in mean rainfall combined with an increase in mean surface temperature and the frequency and intensity of extreme heat events, leads to exacerbated risk of dust storms adversely impacting the performance of tunnel ventilation system.	Low • While there is substantial uncertainty around the direction of change of mean rainfall, some models show a decrease in mean rainfall of at least 15 per cent by 2090 • Mean surface temperature is projected to increase by up to 4.7°C by 2090 • The number of days above 35°C and 40°C are projected to increase by an average of 11 days and two days per year, respectively, by 2090.	Medium • Reduced in tunnel air quality could have adverse impacts on the health of tunnel users and operational personnel • Increased particulate matter could result in reduced performance of tunnel ventilation systems which may require temporary closure of the tunnels, which in turn could have adverse impacts on the road network level of service.	Low

Risk scenario	Likelihood	Consequence	Risk level
Atmospheric CO_2			
Increase in atmospheric CO_2 and the frequency and intensity of extreme heat events leads to accelerated deterioration of ancillary infrastructure (maintenance bays, ventilation facilities, substations) due to corrosion and thermal expansion of steel reinforcement in concrete and thermal expansion of steel, protective cladding, and coatings.	Low • Atmospheric CO_2 is projected to continue to increase • The number of days above 35°C and 40°C are projected to increase by an average of 11 days and two days per year, respectively, by 2090 • Accelerated deterioration rates due to increasing CO_2 and heat extremes are expected to be minor compared to baseline deterioration rates.	Low • Accelerated deterioration could lead to structural damage, which would result in reduced safety operational personnel • While potential impacts would be identified during routine maintenance procedures, accelerated deterioration would result in increased maintenance and operational costs for rectification works. These costs would be anticipated to be low in the scope of the entire project.	Negligible
Increase in atmospheric CO_2 and the frequency and intensity of extreme heat events leads to accelerated deterioration of bridge and surface pavement and structures (retaining walls, batters) due to corrosion and thermal expansion of steel reinforcement in concrete and thermal expansion of steel, protective cladding, and coatings.	Low • Atmospheric CO_2 is projected to continue to increase • The number of days above 35°C and 40°C are projected to increase by an average of 11 days and two days per year, respectively, by 2090 • The proposed structures have a long design life, over a period which projected climate trends are likely to be experienced • Accelerated deterioration rates due to increasing CO_2 and heat extremes are expected to be minor compared to baseline deterioration rates.	Low • Accelerated deterioration could reduce the structural integrity of structures and may result in damage • Deterioration or damage would result in reduced safety for users and operational personnel • While potential impacts would be identified during routine maintenance procedures, accelerated deterioration would result in increased maintenance and operational costs for rectification works. These costs would be anticipated to be low in the scope of the entire project • Closures for increased maintenance may result in adverse impacts on road network level of service.	Negligible

Risk scenario	Likelihood	Consequence	Risk level
Increase in atmospheric CO_2 and the frequency and intensity of extreme heat events leads to accelerated deterioration of the surface drainage system due to thermal expansion and corrosion of steel and reinforced concrete structures.	Low • Atmospheric CO_2 is projected to continue to increase • The number of days above 35°C and 40°C are projected to increase by an average of 11 days and two days per year, respectively, by 2090 • The proposed structures have a long design life, over a period which projected climate trends are likely to be experienced • Accelerated deterioration rates due to increasing CO_2 and heat extremes are expected to be minor compared to baseline deterioration rates.	Low • While potential impacts would be identified during routine maintenance procedures, accelerated deterioration of the concrete and steel components of the surface drainage system could result in increased maintenance costs and potential safety risks. These costs would be anticipated to be low in the scope of the entire project • Damages to the surface drainage system could increase localised flood risk • Increased maintenance may result in increased road/lane closures and adverse impacts on road network level of service.	Negligible
Increase in atmospheric CO_2 and the frequency and intensity of extreme heat events leads to accelerated deterioration of tunnel drainage system due to corrosion of steel and reinforced concrete structures.	Low • Atmospheric CO_2 is projected to continue to increase • The tunnel drainage system has a long design life, over a period which the projected climate trends are likely to be experienced • Accelerated deterioration rates due to increasing CO_2 are expected to be minor compared to baseline deterioration rates • Although temperatures within the tunnel are likely to be influenced by external surface temperatures, the subsurface tunnel is anticipated to maintain a cooler environment compared with external surface temperatures.	Low • While potential impacts would be identified during routine maintenance procedures, accelerated deterioration of the concrete and steel components of the tunnel infrastructure and tunnel drainage system could result in increased operational costs and reduced safety due to increased tunnel flood risk. These costs would be anticipated to be low in the scope of the entire project.	Negligible

Risk scenario	Likelihood	Consequence	Risk level
Bushfire risk			
Increased frequency and intensity of bushfire events due to increased bushfire weather adversely affects performance of tunnel ventilation system and subsequently road users as a result of smoke pollution.	Low • The annual number of days with severe fire danger is projected to increase by 130 per cent by 2090, however the probability that a bushfire will cause smoke pollution that is heavy enough to reduce the performance of the tunnel is low.	Medium • Reduced in tunnel air quality could have adverse impacts on the health and safety of tunnel users and operational personnel.	Low
Increased frequency and intensity of bushfire events leads to failure of communications network due to direct fire damage to network infrastructure.	Medium • The annual number of days with severe fire danger is projected to increase by 130 per cent by 2090, with risk of impacts on communications network infrastructure, leading to indirect impacts on the project through communications outages.	High • Communications outages could result in a loss of operational capability and reduced safety for road users and operational personnel due to unavailability of telecommunication services, particularly in the event of an emergency, with the potential for need for temporary closure of motorway tunnels without these essential services.	High
Increased frequency and intensity of bushfire events leads to failure of power supply infrastructure due to direct fire damage to the energy transmission network.	Medium • The annual number of days with severe fire danger is projected to increase by 130 per cent by 2090, with risk of impacts on power supply infrastructure, leading to indirect impacts on the project through power outages.	High • Power outage could result in traffic delays or reduced safety for road users and operational personnel due to functional failure of powered infrastructure. Powered infrastructure includes tunnel lighting, traffic signals, ventilation facilities, pumping stations, with the potential for need for temporary closure of motorway tunnels without power to these essential systems.	High

Risk scenario	Likelihood	Consequence	Risk level
Extreme heat			
Increase in frequency and intensity of extreme heat events causes higher temperatures within the tunnel for road users.	Low • The number of days above 35°C and 40°C are projected to increase by an average of 11 days and two days per year, respectively, by 2090 • Temperatures within the tunnel would be influenced by external surface temperatures as outside air would be drawn into the tunnel through the portals with the in-coming movement of vehicles and through mechanical ventilation fans. Higher temperatures are likely to be experienced within the tunnel as external surface temperatures increase, particularly on extreme temperature days • Although temperatures within the tunnel are likely to be influenced by external surface temperatures, the tunnel is anticipated to maintain a cooler environment compared with external surface temperatures.	Medium • High tunnel temperatures could have adverse impacts on the health of tunnel users and operational personnel.	Low
Increase in frequency and intensity of extreme heat events leads to reduced efficiency and function of vehicles utilising the tunnel, increasing the number of vehicles overheating and breaking down.	Low • The number of days above 35°C and 40°C are projected to increase by an average of 11 days and two days per year, respectively, by 2090 • The tunnel is anticipated to maintain a cooler environment compared with surface temperatures and the likelihood of heat stress impacts on vehicles is low.	Low • The tunnel design includes breakdown bays and provision of a shoulder on the left and the right side of the road which could be used to provide temporary accommodation for broken down vehicles and access for emergency vehicles.	Negligible

Risk scenario	Likelihood	Consequence	Risk level
Increase in frequency and intensity of extreme heat events increases the risk of heat stress conditions for operational personnel.	Low • Measures to manage heat stress are considered in the project Work Health and Safety Management Plan.	High • Heat stress could have adverse impacts on the health of operational personnel.	Medium
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 • The number of days above 35°C and 40°C are projected to increase by an average of 11 days and two days per year, respectively, by 2090.	Medium • Power outage could result in traffic delays or reduced safety for road users and operational personnel due to functional failure of powered infrastructure.	High
Increase in frequency and intensity of extreme heat events leads to accelerated deterioration of road pavement.	Low • The number of days above 35°C and 40°C are projected to increase by an average of 11 days and two days per year, respectively, by 2090 • The design life of road pavement is short. Road maintenance including resealing would occur at intervals too short for impacts to occur.	Low • Accelerated deterioration of road pavement could result in increased maintenance costs. The thermal tolerance of road pavement is relatively high.	Negligible
Increase in frequency and intensity of extreme heat events leads to reduced efficiency of power generation and transmission, resulting in increased electricity consumption.	High • The number of days above 35°C and 40°C are projected to increase by an average of 11 days and two days per year, respectively, by 2090.	Low • Increased electricity consumption would result in increased operational costs.	Medium

Risk scenario	Likelihood	Consequence	Risk level
Wind speed			
Changes in wind speed adversely affect structural stability of structures on platforms, particularly elevated ramp structures at the Rozelle interchange.	Negligible • Wind speed in not projected to increase more than one per cent by 2090 • A large degree of redundancy is built into the design of elevated ramp structures for structural stability and safety.	Low • Changes in wind speed are unlikely to result in structural damage to elevated structures; however, it may cause minor structural stress.	Negligible
Changes in wind speed adversely affect performance of tunnel ventilation system.	Negligible • Wind speed in not projected to increase more than one per cent by 2090.	Low • The impacts of wind on the performance of tunnel ventilation system would be negligible.	Negligible
Changes in wind speed adversely affect structural stability of ancillary infrastructure such as maintenance bays and substations.	Negligible • Wind speed in not projected to increase more than one per cent by 2090.	Low • A large degree of redundancy is built into the design of infrastructure for structural stability and safety • Increased maintenance may result in increased road/lane closures and adverse impacts on road network level of service • Increased maintenance costs.	Negligible