The Northern Road Upgrade Mersey Road, Bringelly to Glenmore Parkway, Glenmore Park

NSW Environmental Impact Statement / Commonwealth Draft Environmental Impact Statement

Appendix Q – Technical working paper: Greenhouse gas assessment and Climate change risk assessment

June 2017

The Northern Road Upgrade - Mersey Road to Glenmore Parkway

Prepared for NSW Roads and Maritime Services by Jacobs Australia

Climate Change Risk Assessment

Final

15 May 2017

The Northern Road Upgrade - Mersey Road to Glenmore Parkway Upgrade (Mersey Road to Glenmore Parkway)

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Author:	James Moore
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Jacobs Group (Australia) Pty Limited
ABN 37 001 024 095
710 Hunter Street
Newcastle West NSW 2302 Australia
PO Box 2147 Dangar NSW 2309 Australia
T +61 2 4979 2600
F +61 2 4979 2666
www.jacobs.com

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1. Introduction

1.1 Project background

Roads and Maritime is seeking approval to upgrade 16km of The Northern Road between Mersey Road, Bringelly and Glenmore Parkway, Glenmore Park (the project).

The project generally comprises the following key features:

- A six-lane divided road between Mersey Road, Bringelly and Bradley Street, Glenmore Park (two general traffic lanes and a kerbside bus lane in each direction). The wide central median would allow for an additional travel lane in each direction in the future, if required
- An eight-lane divided road between Bradley Street, Glenmore Park and about 100 m south of Glenmore Parkway, Glenmore Park (three general traffic lanes and a kerbside bus lane in each direction separated by a median)
- About eight kilometres of new road between Mersey Road, Bringelly and just south of the existing Elizabeth Drive, Luddenham, to realign the section of The Northern Road that currently bisects the Western Sydney Airport site and to bypasses Luddenham
- About eight kilometres of upgraded and widened road between the existing Elizabeth Drive, Luddenham and about 100 m south of Glenmore Parkway, Glenmore Park
- Closure of the existing The Northern Road through the Western Sydney Airport site
- Tie-in works with the following projects:
  - The Northern Road Upgrade, between Peter Brock Drive, Oran Park and Mersey Road, Bringelly (to the south)
  - The Northern Road Upgrade, between Glenmore Parkway, Glenmore Park and Jamison Road, South Penrith (to the north)
- New intersections including:
  - A traffic light intersection connecting the existing The Northern Road at the southern boundary of the Western Sydney Airport, incorporating a dedicated u-turn facility on the western side
  - A traffic light intersection for service vehicles accessing the Western Sydney Airport, incorporating 160 m of new road connecting to the planned airport boundary
  - A traffic light intersection connecting the realigned The Northern Road with the existing The Northern Road (west of the new alignment) south of Luddenham
  - A 'give way' controlled intersection (that is, no traffic lights) connecting the realigned The Northern Road with Eaton Road (east of the new alignment, left in, left out only)
  - A four-way traffic light intersection formed from the realigned Elizabeth Drive, the realigned The Northern Road and the existing The Northern Road, north of Luddenham
  - A traffic light intersection at the Defence Establishment Orchard Hills entrance, incorporating a u-turn facility
- New traffic lights at four existing intersections:
  - Littlefields Road, Luddenham
  - Kings Hill Road, Mulgoa
  - Chain-O-Ponds Road, Mulgoa
  - Bradley Street, Glenmore Park incorporating a u-turn facility
- Modified intersection arrangements at:
  - Dwyer Road, Bringelly (left in, left out only)
  - Existing Elizabeth Drive, Luddenham (left out only)

- Gates Road, Luddenham (left in only)
- Longview Road, Luddenham (left in, left out only)
- Grover Crescent south, Mulgoa (left in only)
- Grover Crescent north, Mulgoa (left out only)

- Dedicated u-turn facilities at:
  - The existing The Northern Road at Luddenham, south-west of Elizabeth Drive
  - The existing Elizabeth Drive, Luddenham around 800 m east of The Northern Road
  - Chain-O-Ponds Road, Mulgoa
- Twin bridges over Adams Road, Luddenham
- Local road changes and upgrades, including:
  - Closure of Vicar Park Lane, east of the realigned The Northern Road, Luddenham
  - Eaton Road cul-de-sac, west of the realigned The Northern Road, Luddenham
  - Eaton Road cul-de-sac, east of the realigned The Northern Road, Luddenham
  - Elizabeth Drive cul-de-sac, about 300 m east of The Northern Road with a connection to the realigned Elizabeth Drive, Luddenham
  - Extension of Littlefields Road, east of The Northern Road, Mulgoa
  - A new roundabout on the Littlefields Road extension, Mulgoa
  - A new service road between the Littlefields Road roundabout and Gates Road, including a 'give way' controlled intersection (that is, no traffic lights) at Gates Road, Luddenham
  - Extension of Vineyard Road, Mulgoa between Longview Road and Kings Hill Road
  - A new roundabout on the Vineyard Road extension at Kings Hill Road, Mulgoa
- A new shared path on the western side of The Northern Road and footpaths on the eastern side of The Northern Road
- A new shared path on the western side of The Northern Road and footpaths on the eastern side of The Northern Road where required
- The upgrading of drainage infrastructure
- Operational ancillary facilities including:
  - Heavy vehicle inspection bays for both northbound and southbound traffic, adjacent to Grover Crescent, Mulgoa and Longview Road, Mulgoa respectively
  - An incident response facility on the south-western corner of the proposed four-way traffic light intersection at Elizabeth Drive, Luddenham
- New traffic management facilities including variable message signs (VMS)
- Roadside furniture and street lighting
- The relocation of utilities and services
- Changes to property access along The Northern Road (generally left in, left out only)
- Establishment and use of temporary ancillary facilities and access tracks during construction
- Property adjustments as required
- Clearance of undetonated explosive ordinance (UXO) within the Defence Establishment Orchard Hills as required.

The project assessed in this EIS does not include surveys, test drilling, test excavations, geotechnical investigations or other tests, surveys, sampling or investigation for the purposes of the design or assessment of the project.

The upgrade of The Northern Road is part of the Western Sydney Infrastructure Plan (WSIP). The WSIP involves major road and transport linkages that will capitalise on the economic gains from developing the Western Sydney Airport site at Badgerys Creek whilst boosting the local economy and liveability of western Sydney.

Jacobs Group (Australia) Pty Ltd (Jacobs) was commissioned by Roads and Maritime Services (Roads and Maritime) to undertake an assessment of the potential environmental impacts of the project, and prepare an Environmental Impact Statement (EIS) is accordance with the *Environmental Planning and Assessment Act 1979* (EP&A Act) that adequately addresses the *Secretary's Environmental Assessment Requirements* (SEARS) issued 9 March 2016 and the Commonwealth EIS Guidelines issued 5 August 2016. This document presents the Climate Change Risk Assessment for the project.

1.2 Location of project area

The Northern Road is about 45 km west of the Sydney central business district and traverses the local government areas of Penrith in the north and Liverpool in the south.

The Northern Road is a key north–south road between Narellan and Richmond, connecting the North West and South West Priority Growth Areas. The corridor intersects with a number of regional motorways, arterial and collector roads such as (north to south) Richmond Road, Great Western Highway, M4 Motorway, Elizabeth Drive, Bringelly Road, and Camden Valley Way.

South of Glenmore Parkway, the project area is surrounded by rural residential zoned land as well as pastures and grasslands. Land to the east of The Northern Road in this section is occupied by the Commonwealth Defence Establishment Orchard Hills. Further south, The Northern Road passes through the village of Luddenham (including a small number of residential and commercial properties), before continuing through agricultural grasslands to its junction with Mersey Road (the northern extent of The Northern Road Upgrade between Peter Brock Drive, Oran Park and Mersey Road, Bringelly).

A seven kilometre section of the existing The Northern Road alignment bisects the Western Sydney Airport site south-east of the Luddenham town centre.

1.3 About this report

This *Climate change scenarios and projections report* provides a description of the historical climate experienced at the project area (**Section 3**) and of how it may change in response to climate change (**Section 4**). The report establishes the current and potential future climatic context for an assessment of key climate change risks to which the project may be exposed. This risk assessment will form the basis of climate change adaptation planning for incorporation into the project's Reference Design.

Most of the climate change projections are based on meteorological records for Bureau of Meteorology (BoM) station: Richmond RAAF Base, which was originally coded 67033, but replaced in 1994 with new station 67105. This station was chosen as it has the longest continuous record of rainfall and temperature observations of all BoM stations close to the project. Climate records from this site are likely to reliably represent those experienced across the project area.

This report also includes some background information on: drivers of climatic variability in south-eastern Australia, process associated with climate change; and the development and use of climate change projections (**Section 0**). Historical climate for the project area is presented (**Section 3**) before climate change projections are shown (**Section 4**). Details of the process for undertaking a climate change risk assessment, and the assessment itself is presented in **Section 5**, followed by details of mitigations measures (**Section 6**).

2. Climate and climate change

2.1 Drivers of regional climate variability

Year-to-year variations in sea surface temperatures (SST) and air pressure in oceans surrounding Australia and variations in atmospheric circulation exert powerful influences on Australia's climate (see Figure 2-1). They contribute to the significant inter-annual variability in climate and recurring cycles of drought and flood.

The El Niño and La Niña phases of the El Niño-Southern Oscillation (ENSO) are associated with contrasting patterns of rainfall and air temperature in eastern Australia. The El Niño phase of ENSO is associated with marked reductions in rainfall and increased air temperatures. La Niña events are typically associated with enhanced rainfall and cooler air temperatures (Kiem and Franks, 2001; Verdon *et al. 2004*). SST fluctuations in the Indian Ocean (related to the Indian Ocean Dipole, IOD) have similar influences and are correlated with rainfall variability between August and April in Southern Australia (Verdon and Franks, 2005).

Eastwards moving high and low pressure systems that cross the continent and Great Australian Bight exert an important influence on Australia's weather. Continental and tropical influences, including the rain-bearing north-west cloud bands and East Coast lows (see Figure 2-1) also influence NSW's weather.

Winter rains in the region occur when the sub-tropical high pressure belt (the sub-tropical ridge [STR]; Figure 2-1) is displaced to the north and allows low pressure systems and cold frontal activity to penetrate. The STR moves to the south during summer, which displaces frontal systems to the south and contributes to the relatively wetter weather through this time of year in NSW.

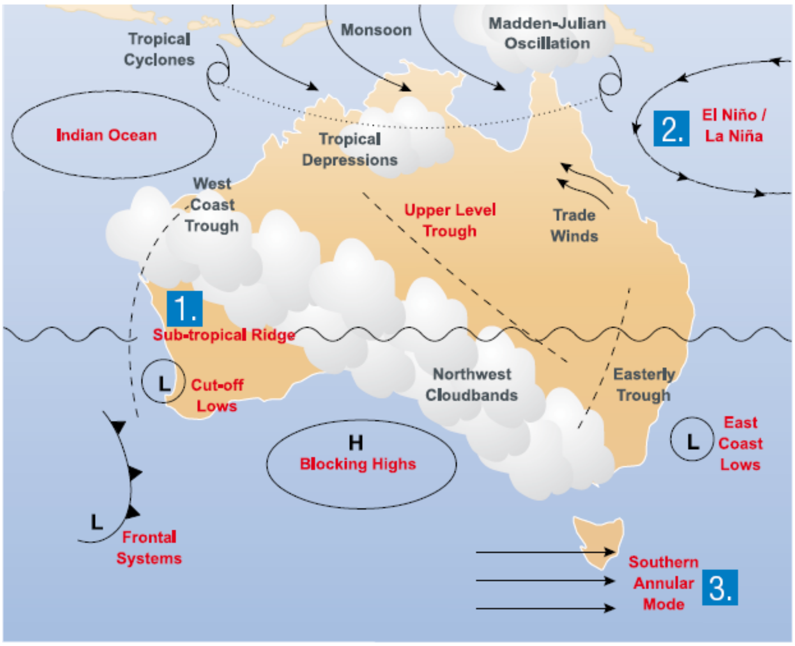


Figure 2-1 Major influences on climatic variability in Australia.

Rainfall in southern Australia (south of the sub-tropical ridge) is influenced by frontal and low pressure systems in the Southern Ocean, pressure systems that move southwards along the east and west coasts and cloud bands extending from the north-west of the continent. (Source: Bureau of Meteorology, www.bom.gov.au/watl/about-weather-and-climate/australian-climate-influences.htm)

Blocking high pressure systems can result in the build-up of heat in the interior of Australia. During summer they can be responsible for extended periods of extreme heat and dangerous fire weather conditions.

2.2 Climate change

Carbon dioxide (CO_2) is a vital gas for photosynthesis and global climate regulation. Since CO_2 and other "greenhouse gases" trap long wave radiation, changes in their concentrations in the atmosphere will influence the Earth's radiation balance and contribute to the warming of both the atmosphere and the Earth's surface. This phenomenon is known as the greenhouse effect.

Atmospheric CO_2 varies annually, reflecting seasonal photosynthetic activity, its release or uptake from the ocean and fires in forests and tropical savannahs. In the past 650,000 years, CO_2 concentrations have varied between 180 and 300 ppm. Since the industrial revolution, concentrations have risen from about 280 ppm to over 400 ppm.

The combined radiative forcing (the effect of greenhouse gases on global radiation balance) of greenhouse gases such as carbon dioxide, methane and nitrous oxide increased almost fourfold between 1950 and 2011 (0.6-2.3 W/m^2), including an increase of almost 50 per cent from 2007. The warming effect of increased atmospheric greenhouse gas concentrations is considered to have contributed to the observed increase in global mean temperature of 0.7°C from 1880 (IPCC, 2013).

2.3 Climate change projections

Climate change projections are derived using general circulation models (often referred to as global climate models or GCMs), which simulate the ocean, atmospheric and land surface processes which influence climate. The models are run under historical conditions and with scenarios representing long-term trajectories for greenhouse gas emissions or their effect on radiative forcing.

GCMs simulate climate at a global scale, typically based on grid cells with a resolution of 200-300 km. Regional climate models (RCMs) use 'down-scaling' techniques to provide climate projections at much finer resolution and better account for topographic and other local climatic influences. RCMs depend on the outputs of GCMs and while their outputs have better spatial resolution they do not necessarily produce more accurate projections than GCMs.

2.3.1 Emissions scenarios

Climate modelling for the *Fourth Assessment Report* (AR4) of Intergovernmental Panel on Climate Change (IPCC) was framed around a series of emissions scenarios which incorporate potential mitigation efforts, population and economic growth trajectories (IPCC, 2007). Modelling for the recent *Fifth Assessment Report* (AR5; IPCC, 2013) is based on *Representative Concentration Pathways* (RCP). The RCPs are identified by the 21st century peak or stabilisation value of radiative forcing (RF, in W/m^2). These scenarios include natural and anthropogenic influences on RF, short and long-lived greenhouse gases and continue to 2300.

Four RCP scenarios have been selected for publication in AR5: RCP2.6, RCP4.5, RCP6 and RCP8.5. The peak RF for RCP2.6 is 3 W/m^2, however in this scenario RF declines to 2.6 W/m^2 by 2100. RCP4.5 and RCP6 follow RF trajectories that are similar to the low and medium emissions scenario used in AR4. At 2100, RCP8.5 is similar to the high emissions A2 and A1FI scenarios used in AR4. In common with the earlier scenarios, there are only relatively small differences in RF and global warming between the RCP scenarios to about 2030. RCP4.5 and RCP6 scenarios follow a similar trajectory in RF until about 2060.

2.3.2 Climate change projections

Under future emissions scenarios, global mean temperatures are projected to increase by up to 4.8°C above 1986-2005 levels by 2100 (Figure 2-2). Warming over land, particularly in the Arctic region, is projected to be greater than warming over oceans. It is virtually certain that there will be more hot temperature extremes and fewer cold temperature extremes over most land areas on daily and seasonal timescales (IPCC, 2013).

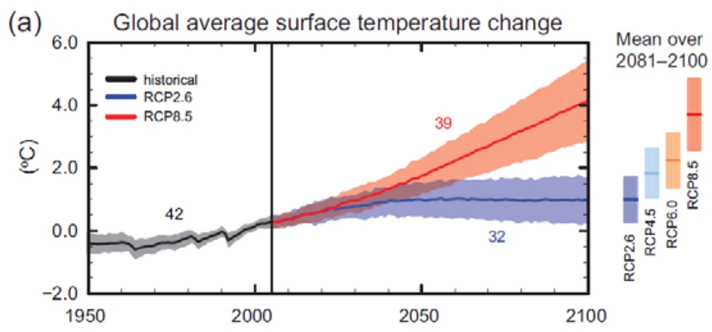


Figure 2-2 Global warming projections under various RCP scenarios to 2100.

Bars on the right hand side show the variation in estimates across the full ensemble of GCMs. Source: IPCC 2013

The global water cycle will continue to be strongly influenced by natural climatic variability. Precipitation is likely to increase in some regions and decrease in others. Extreme precipitation events over most mid-latitude land masses and wet tropical regions will very likely become more intense and frequent by the end of the century as temperature and atmospheric moisture increase. Monsoon rainfall is likely to intensify and the duration of monsoon seasons will likely be extended in many regions.

While ENSO-related precipitation variability will likely intensify, the level of confidence in projections regarding any specific change in the phenomenon is low. However, there is now emerging evidence that the frequency of extreme El Niño events may increase significantly (Cai *et al*., 2014). Should this occur, the incidence of severe droughts, heatwaves and fire weather conditions in NSW – which are common expressions of extreme El Niño events – could increase. The effect of climate change on ECLs is expected to decrease the number of small to moderate ECLs in the cool season with little change in these storms during the warm season. However, extreme ECLs in the warmer months may increase in number but extreme ECLs in cool seasons may not change [1].

Oceans are projected to continue to warm, with heat penetrating to the deep ocean, particularly in the Southern Ocean. Warming of the ocean and melting of continental ice sheets will contribute to further rises in sea levels. Sea level rise will likely be in the range 0.26-0.55 m for RCP2.6 and 0.45-0.82 m for RCP8.5 for 2081-2100 (compared with 1986-2005). The projected rise by 2100 is 0.52-0.98 m for RCP8.5. Sea level rise is not expected to be uniformly distributed across the globe.

[1] http://www.climatechange.environment.nsw.gov.au/Impacts-of-climate-change/East-Coast-Lows/Future-East-Coast-Lows

3. Historical climate for the project area

3.1 Introduction

Understandings of natural climatic variability and projected climate change are important inputs into the assessment of climate change risk and the development of effective strategies to adapt to climate change. This section describes the project area's historical climate, based on meteorological observations from BoM stations 67033 and 67105, located at RAAF Richmond (67033 operated from 1928 until 1994, and 67105 operated from 1994 until present). RAAF Richmond is located approximately 20km north of the project, but is the nearest BoM station with a significant level of historical climate data available (i.e. > 20 years). Rainfall observations are available for the years 1928-2015 and temperature observations are available for the years 1939-2015. No readings were available for the period 1947 to 1952. Observations of wind speed are available 1939 to present - although not for all statistics.

3.2 Climate profile development

An historical climate profile has been developed for the project area. It describes characteristics of western Sydney's climate which are relevant to the assessment of potential climate change impacts on the project, as follows:

- *Rainfall*: annual rainfall, monthly average rainfall and maximum daily rainfall in each month
- *Temperature:* annual and monthly maximum, average and minimum temperature. The incidence and severity of heatwaves is also reported, in terms of excessive daily maximum temperatures and a heatwave severity index (Nairn and Fawcett, 2013). Low temperature incidence is also reported
- *Wind:* average daily wind speed for each month and maximum wind gust by month over the period of record.

Rainfall and temperature conditions are reported for two periods, the full length of records available (see 3.1 above) and the reference period for AR5 climate change projections, 1986-2005. Climate change projections provide estimates of the change in average conditions from this 20 year period.

3.3 Rainfall

3.3.1 Annual rainfall

Annual rainfall for western Sydney over the period of record 1928-2015 is summarised in Table 3-1. Average annual rainfall of the full period of record is 780 mm. Annual rainfall has ranged between 293 mm in 1940 and 1,466 mm in 1963. Rainfall has exceeded 1000 mm in eleven of the 81 years of record and been less than 400 mm in three years. The record of annual rainfall shows the influence of multi-year climate cycles, with extended periods of relatively dry (e.g. late 1990s and early 2000s) and relatively wet (1950s) weather evident (Figure 3-1).

Average rainfall during the climate change projection reference period (1986-2005) is slightly greater than the long term average, at 794 mm. Rainfall has only ranged between 521 and 1,352 mm over that period. None of the three years with less than 400 mm annual rainfall occurred during the climate change reference period.

Table 3-1: Summary of historical annual rainfall for western Sydney. Source: BoM stations 67033 and 67105

	1928-2014	Year	1986-2005	Year
Maximum (mm)	1,466	1963	1,352	1990
Mean (mm)	780		794	
Minimum (mm)	296	1940	521	1993

Western Sydney's rainfall has trended downwards over the period of record, with an average reduction in annual rainfall of almost 2.7 mm/decade over the almost 160 years. The high level of year-to-year variability in rainfall means that this trend is not statistically significant.

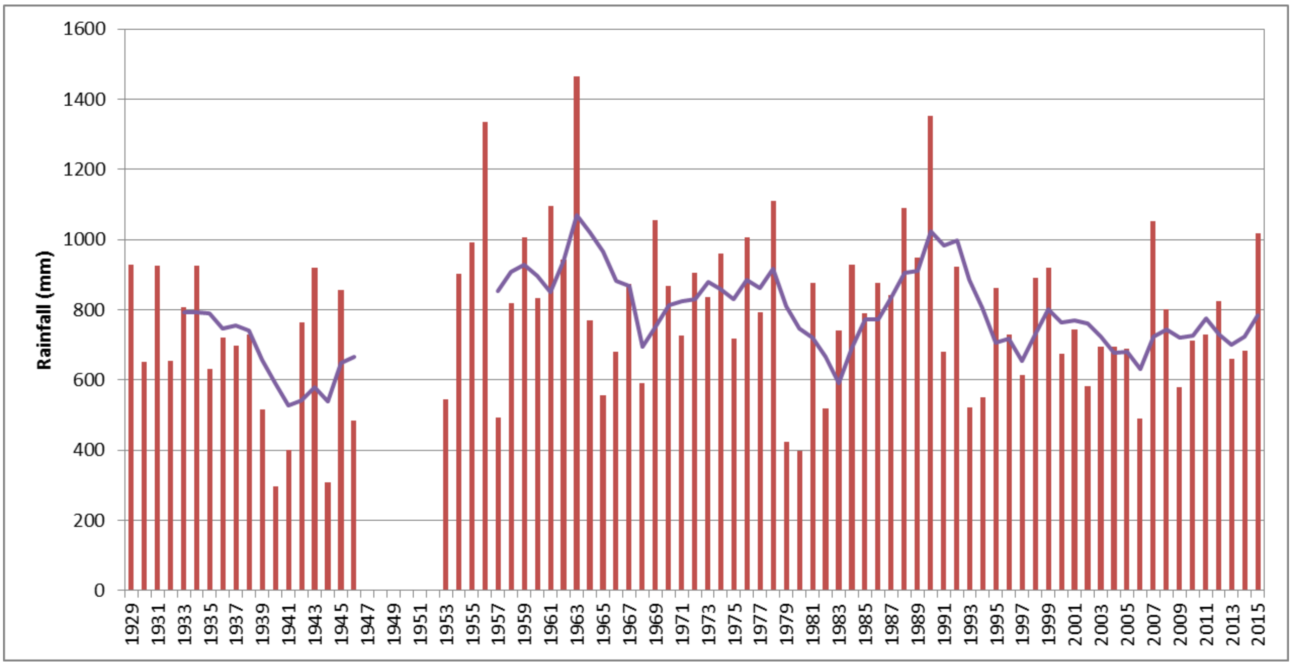


Figure 3-1 Annual rainfall for western Sydney (RAAF Richmond)

Source: BoM stations 67033 and 67105. Graph plots total annual rainfall and the five year moving average of annual rainfall. The latter highlights the influence of multi-year climate cycles, such as ENSO.

3.3.2 Monthly rainfall

Over the full length of record, average monthly rainfall ranges between 34.1 mm in July and 109.8 mm in February (Figure 3-2). Average monthly rainfall during winter (particularly June and July) is considerably lower than the average for summer, where rainfall approximately doubles.

Every month has received less than 10 mm of rain at some stage over the period of record. Every month except five (January, February, April, May and November) have received less than 1 mm of rain. Tenth percentile of rainfall for each month ranges between 3.4 mm in August and 21.5 mm in January. The winter months (and the months either side) see the 10th percentile rainfall drop into single digits (Figure 3-2).

Rainfall totals exceeding 100 mm have been recorded in every month of the year, with monthly totals exceeding 200 mm being recorded in all months except July and September. The 90th percentile of monthly rainfall ranges between 74.0 mm in July and 239.7 mm in February. The pattern in extreme monthly rainfalls (Figure

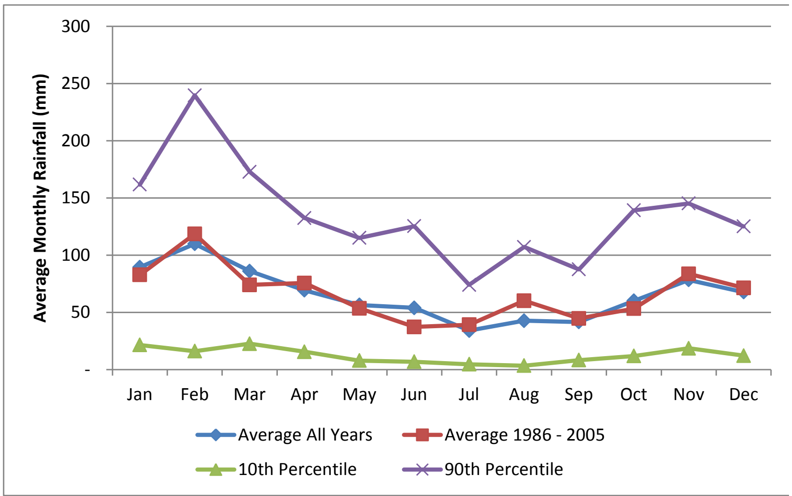


Figure 3-2 Average and extreme monthly rainfall totals for western Sydney.

Source: BoM stations 67033 and 67105. Graph shows average monthly rainfall for RAAF Richmond at western Sydney, as well as the 10th and 90th percentile of monthly rainfall totals for each month. The latter are provided as an indication of rainfall variability. They are the monthly rainfall totals which are exceeded in 10 and 90 per cent of months, respectively.

3-2) indicates that the potential for very wet months is highest during summer.

Western Sydney's pattern of rainfall during the climate change projection reference period (Figure 3-2) follows that of the long-term average reasonably closely. Average monthly rainfall over this period ranged between 37.3 mm in June and 118.4 mm in February.

3.3.3 Daily rainfall

Maximum recorded daily rainfall totals are typically greater during summer-autumn than at other times of year (Figure 3-3), which reflects that the warmer air is able to hold more water. The spike in August relates to western Sydney's greatest day of rainfall on record (6 August 1986).

Daily rainfall totals in excess of 100 mm have been recorded twenty one times since 1929 in western Sydney. Daily totals greater than 50 mm have been recorded in every month.

The climate change projection reference period includes the highest daily rainfall total for western Sydney and several other exceptionally wet days (Figure 3-3). However, maximum daily rainfall totals are typically 20-50 mm or more lower that those recorded over the full period of record.

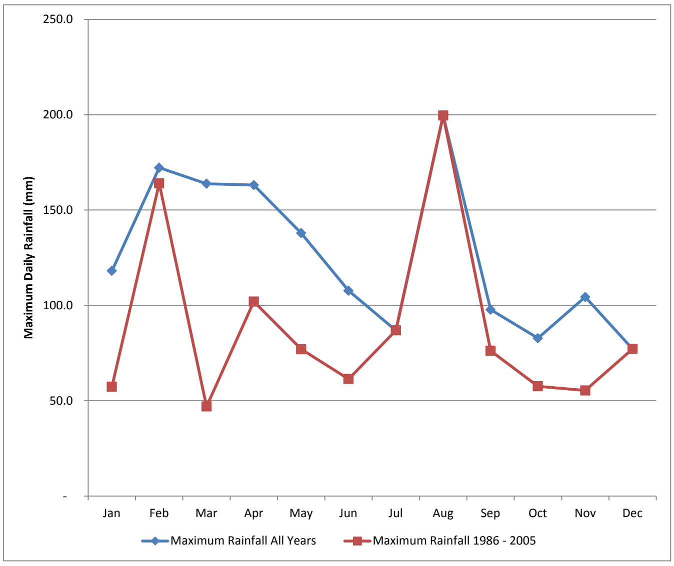


Figure 3-3 Highest recorded daily rainfall totals for western Sydney.

Source: BoM stations 67033 and 67105.

3.4 Temperature

3.4.1 Annual temperature

The average temperature in western Sydney over the period of record 1929 - 2015 is 17.2°C (Table 3-2). The annual average maximum and minimum temperatures are 23.5°C and 10.9°C, respectively. Recorded temperatures in western Sydney have ranged between -8.3°C (21/7/1869) and 46.4°C (7/2/2009).

Table 3-2: Maximum, average and minimum temperatures (°C) for western Sydney.

	1940-2014	1986-2005
Maximum observed Tmax	46.4	44.9
Average Tmax	23.5	23.9
Average temperature	17.2	17.5
Average Tmin	10.9	11.0
Minimum recorded Tmin	-8.3	-5.8

Source: BoM stations 67033 and 67105. Table includes a comparison of the full period of record and the 1986-2005 climate change projection reference period. Tmax – maximum temperature; Tmin – minimum temperature.

The highest temperature in each year over the period of record (Figure 3-4) averages 41.4°C, with a range of 37.0°C to 46.4°C. The lowest recorded temperature in each year ranges between -8.3°C and -0.4°C, with an average of -2.7°C. Annual average maximum and minimum temperatures have ranged between 21.3°C and 25.4°C and 9.7°C and 12.0°C, respectively. Variability in annual maximum temperatures is greater than variability in averages or minima.

There are consistent trends for increased maximum, and decreased minimum temperatures since 2000 (Figure 3-4). This trend is most obvious for maximum and minimum recorded temperatures.

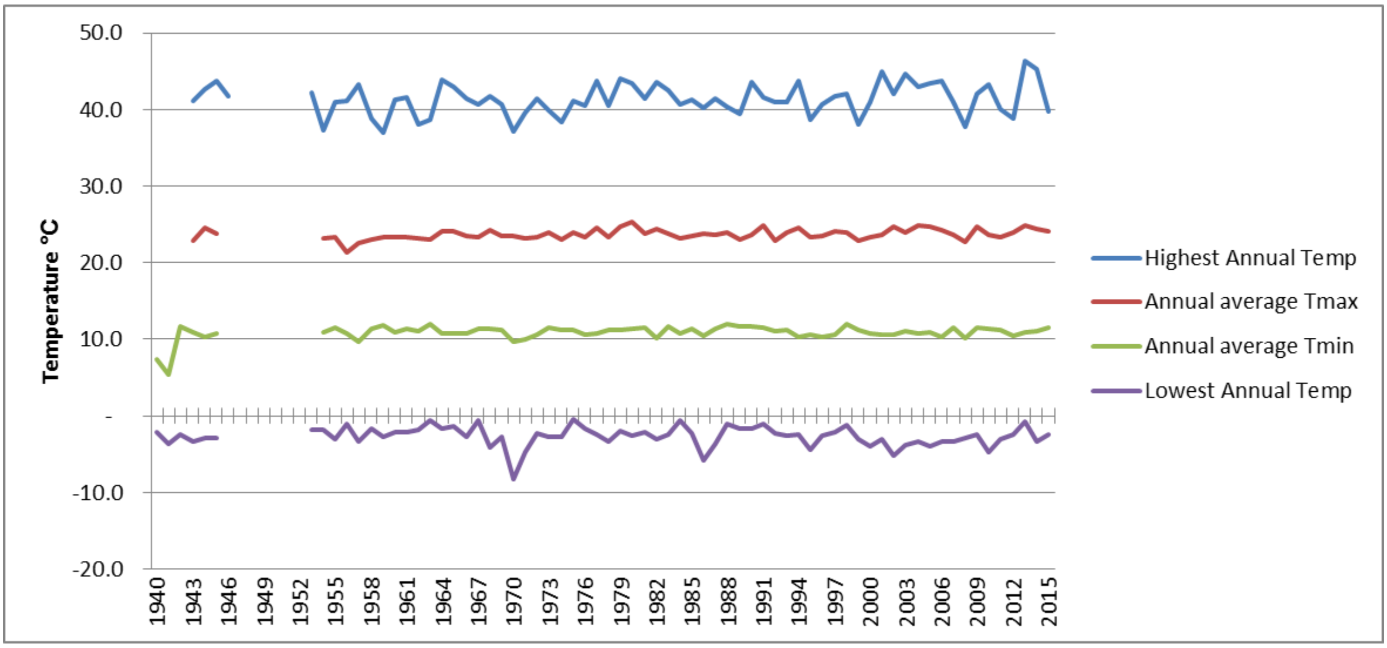


Figure 3-4 Temperature records for RAAF Richmond, western Sydney

Source: BoM station 67033 and 67105. Data presented for highest and lowest temperatures recorded each year and average Tmax (daily maximum temperature) and Tmin (daily minimum temperature) for each year of record, 1940-2015.

Average temperatures over the climate change projection reference period (Table 3-2) are 0.1°C to 0.4°C warmer than over the entire period of record. The highest recorded value of maximum temperature is less than for the full period of record, but the lowest minimum is warmer.

3.4.2 Monthly temperatures

Average maximum temperatures in western Sydney range between 19.1°C in August and 29.7°C in January (Figure 3-5), with the highest recorded temperatures in each month varying between 26.6°C in June and 46.4°C in January. Maximum temperatures over 40°C have been recorded in each month between October and March.

Average monthly temperature ranges between 10.5°C in July and 23.7°C in January.

Average monthly minimum temperatures range between 3.6°C in July and 17.6°C in January. The lowest recorded temperatures range between -8.3°C in July and 9.5°C in February. Freezing temperatures have been recorded each month between April and September (Figure 3-5).

Figure 3-5 Monthly temperature profile for western Sydney.

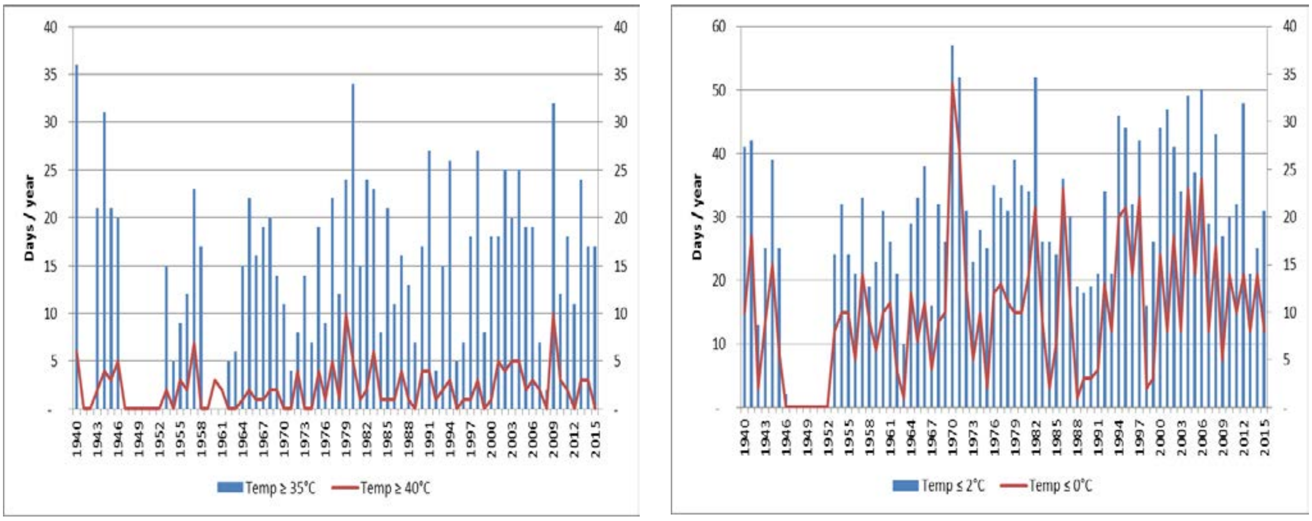
Source: BoM stations 67033 and 67105. Figure plots maximum and minimum temperatures recorded in each month (Tmax/Tmin recorded), monthly average temperature and average monthly maximum and minimum temperature (Tmax/Tmin).

Monthly average and minimum temperatures for the climate change projection reference period are typically higher than those for the full period of record. Average monthly maximum temperatures are generally lower.

3.4.3 Daily maximum temperature extremes

Days in which maximum temperatures exceed 35°C and 40°C are reasonably common in western Sydney. On average, there are 14.5 and 2.1 days/y, respectively, on which daily maximum temperatures reach or exceed the two benchmark temperatures. The years with the greatest number of days with temperatures of 40°C or more (ten) was 1979 and 2009 (Figure 3-6).

The average incidence of days on which maximum temperatures reach or exceed 35°C or 40°C during the climate change projection reference period is 16.3 and 2.4 days/y, respectively, and is slightly higher than the full period of record.



a) Incidence of days with maximum temperatures of 35°C or 40°C or more.

b) Incidence of days with minimum temperatures of 0°C or 2°C or less.

Source: BoM station 086071. Note that 1947 to 1952 inclusive have no data.

Figure 3-6 Incidence of days for western Sydney with extreme low or high temperatures.

3.4.4 Daily minimum temperature extremes

Days in which minimum temperatures are 2°C or less are more common in western Sydney than extreme heat days. On average, there have been 28.5 days/y with temperatures at or below this temperature over the period of record and 10.0 days/y with freezing temperatures (0°C or below). The incidence of such days in western Sydney increased slightly since the 1980s (Figure 3-6)

The average incidence of days with minimum temperatures of 2°C or less during the climate change projection reference period is 32.8 days/y, compared with 28.5 days/y for the full length of record.

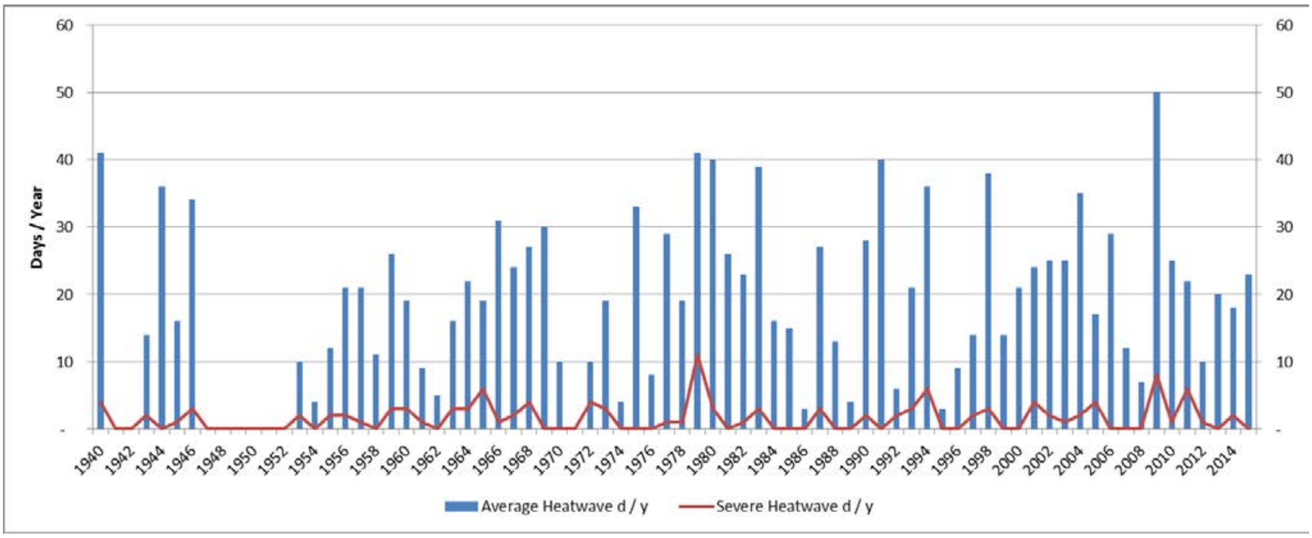
3.4.5 Heatwaves

While they are a common natural hazard in Australia, heatwaves are not precisely-defined events. In its most basic form, a heatwave may be defined as an event with at least two consecutive days of high temperature. Various benchmarks for “high temperature” may be used: 35°C or 40°C (as above). In South Australia, the trigger point for heatwave-linked Extreme Heat Plans is three or more consecutive days where the average of daily maximum and minimum temperatures is at least 32°C (SA State Emergency Service, 2013). This latter measure takes account of the observation that human health and other issues associated with heatwave events increase where high overnight temperatures provide limited relief from extreme daytime heat loadings.

Nairn and Fawcett (2013) noted that heatwave intensity occupies a continuum between low-intensity heatwaves, which have little impact, and more intense events which may have severe consequences for the community, economy and/or infrastructure. Heatwave impacts also vary according to local experience of excess heat and the existence or effectiveness of resilience strategies. By determining heatwave intensity, it is possible to differentiate between heatwave events and analyse the effectiveness of resilience strategies.

Nairn and Fawcett (2013) developed a heatwave concept that is applicable at any location and which acknowledges that perceptions of heat loading reflect local experiences. Excess heat may therefore occur at a much lower temperature at a cool climate location than in one with a warmer climate. Nairn and Fawcett (2013) calculated an excess heat factor (EHF) which accounts for two main forms of thermal stress: that arising when the long-term thermal resilience of a system is overcome (i.e. when the weather is unusually hot for that location) and that which occurs when a heatwave event is unusual in relation to antecedent heat exposure (which helps to condition people to heat). A heatwave day is identified by positive EHF values. A severe heatwave is considered to be one in which EHF exceeds the 85^{th} percentile (EHF_{85}) of positive values.

The annual frequency of heatwave and severe heatwave days during the period of record for western Sydney is plotted in Figure 3-7. Over the period of record there has been an annual average of almost 18 heatwave days and 2 severe heatwave days. The maximum recorded number of heatwave and severe heatwave days is 50 days/y (in 2009) and 7 days/y (in 1979), respectively.



Source of underpinning data: BoM stations 67033 and 67105. Note that 1947 to 1952 inclusive have no data.

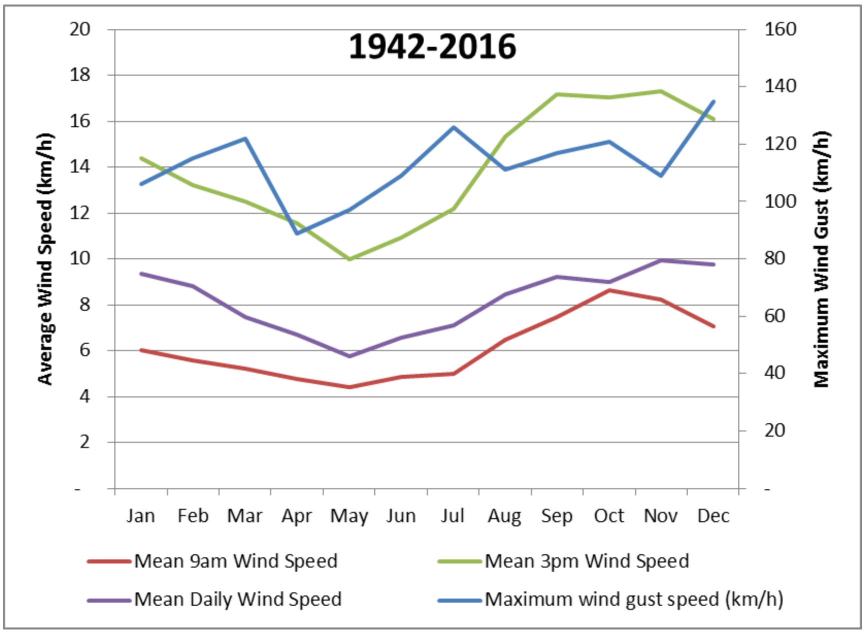
Figure 3-7 Annual incidence of heatwave (EHF>0) and severe heatwave days ($EHF>EHF_{85}$) for western Sydney.

The average incidence of severe heatwave days during the climate change projection reference period 1.7 days/y is slightly lower than that over the full period of record.

3.5 Wind

Wind speeds in western Sydney typically increase through the day (Figure 3-8) with 9 am wind speed typically about 5 km/h lighter than those at 3 pm. Average daily wind speed is similar to the 9 am value, except during spring. Monthly average wind speeds are lowest through late autumn and winter and highest during spring.

Maximum recorded wind gusts in western Sydney range between 97 km/h in May and 135 km/h in December.



Source: BoM stations 67033 and 67105. Graph presents average daily wind speed (from 24 h wind run measurements), average 9 am and 3 pm wind speeds and maximum recorded wind gust for each month.

Figure 3-8 Monthly patterns in wind speed for western Sydney

4. Climate change projections

4.1 Climate change analysis

The IPCC's *Fifth Assessment Report* (IPCC, 2013) provides a synthesis of climate change modelling undertaken by leading international climate research organisations. Outputs from this work for Australia are available on websites managed by CSIRO and BoM (www.climatechangeinaustralia.gov.au). They consolidate projections from GCM runs for the 21st century under a range of greenhouse gas emissions and RCP scenarios and include data for a wide range of climate parameters, including rainfall, temperature and wind speed.

Variability in climate projections reflects several important influences, as follows:

- *Greenhouse gas emissions scenario:* climate change projections for AR5 are based on RCP scenarios (see **Section 2.3**), which describe changing patterns in radiative forcing associated with atmospheric greenhouse gas concentrations through and beyond the 21st Century. Global temperatures are projected to increase more rapidly and to a greater extent under the higher RCP scenarios
- *Sensitivity of the global climate system to increased greenhouse gas concentrations:* GCMs may incorporate varying degrees of sensitivity of global climate to increasing greenhouse gas emissions, with greater sensitivity resulting in a more rapid increase in temperature per unit increase in greenhouse gas concentrations or radiative forcing
- *GCM representation of the global climate system:* the various climate models include differing mathematical representations of the global climate system and may produce quite different results for the same timeframe, RCP scenario and climate sensitivity. Not all of the GCMs have good predictive skill for south-eastern Australia in that they do not necessarily reproduce key drivers of weather and climate in this region.

GCM outputs are reported as 'climate change factors', which are an amount or percentage of change in a particular climate variable for a given time and RCP scenario for a single model or ensemble of models. They represent change from a baseline or reference period, which for AR5 is 1986-2005. Climate change factors are typically the average change from the reference period over a 20 year period that is centred on the reported year[2]. They may be used to adjust an historical sequence of climate variables over the reference period to develop a new climate sequence or climate change projection.

Climate change factors used in this report were derived using the *Climate Futures Tool* (CFT; accessed via www.climatechangeinaustralia.gov.au). An initial filtering of GCM was undertaken to exclude modelling for AR4 and models which the web site advised were not suitable for the east coast region. The CFT was then used to identify the general pattern of climate change projections for 2030 and RCP8.5, with respect to changes in rainfall and temperature. This identified a central tendency for conditions to be warmer (0.5-1.5°C temperature increase), with a slight reduction in rainfall (~5 per cent).

4.2 Uncertainty in climate change projections

Climate change projections are useful tools to guide decision-making about climate risks. They indicate the expected trend in climate variables under various future scenarios and the likely quantum of change. While probabilities may be provided for GCM projections for given RCP or emissions scenarios, no probabilities can be attached to the scenarios themselves.

Climate change projections reported here have not been produced by "downscaling". Climate change factors have simply been used to adjust historical climate records for the 1986-2005 reference period. Various other methods (e.g. use of regional-scale climate models or statistical downscaling techniques) may be used to produce climate change projections with much finer resolution than those derived solely from GCM. While this may be useful, such projections are subject to the uncertainties inherent in the GCM, as well as the additional

[2] Climate change factors for 2030 are the difference in the relevant climate variable between the 1986-2005 average and the projected average for 2021-2040 (for a given RCP scenario).

uncertainties inherent in their own methodologies. While the increased spatial resolution that may be achieved conveys an impression of greater accuracy, this is not necessarily the case.

The reliability of climate change projections varies between climate variables. In general, global projections are more certain than regional projections and temperature projections are more certain than those for rainfall. Changes in average conditions are also more certain than changes in extremes.

4.3 Climate change projection overview

Climate change projections included in this assessment are based on RCP8.5, which reflects the highest of the emissions (or radiative forcing) scenarios considered in AR5. They follow the projections for this scenario through time from 2030 to 2090.

The CFT determines the distribution of GCM change factors for each projection period and classifies models according to changes in average annual temperature and rainfall. The central tendency for the set of models which reliably reflect key climate drivers for south-eastern Australia is for warmer conditions, with little change in rainfall relative to 1986-2005, by 2030. By 2050, the central tendency in GCM projections is for the climate to be warmer and drier than the reference period. A significant number of models project a hotter and drier climate or a warmer climate with little change in rainfall. In 2090, the most common projection is for climate to be much hotter and much drier than during the 1986-2005 climate change reference period. The next most common projection was for climate to be much hotter and much drier. Only a few (7 of 29) of the models which capture the key drivers of south-eastern Australian climate project that rainfall will increase in this region, relative to 1986-2005.

The GCMs selected as most able to model Australian East Coast climate were used to develop climate change projections to 2090 (as determined through commentary provided within the CFT). It is anticipated that the three scenarios included in this analysis represent a plausible range in projections for the course of the 21st century. They capture the central tendency for changes in rainfall and temperature for a lower radiative forcing scenario (RCP4.5) for 2030, 2050 and 2090. While some models project the lower emissions scenario will result in wetter conditions, this is not reflective of the broader group of more reliable models.

4.4 Climate change projections for rainfall

Despite selection of GCM which are able to represent key drivers of climate and weather in south-eastern Australia (e.g. ENSO, blocking highs, East Coast lows), climate change projections for rainfall are inherently uncertain. Those for extreme precipitation are particularly so. The following sections present climate change projections for annual rainfall, monthly rainfall patterns and daily extreme rainfall for western Sydney, based on data for the climate change reference period for BoM stations 67033 and 67105. They are based on seasonal climate change factors derived using CSIRO's Climate Futures Tool.

4.4.1 Annual rainfall

Projected changes in rainfall for western Sydney are shown in Table 4-1. Little change in rainfall is projected for 2030 and the climate is projected to become drier in 2050 and 2090 (by 6.1 per cent and 8.4 per cent, respectively). Due to differing directions of changes in seasonal rainfall in 2030, maximum annual rainfall is projected increase very slightly between the baseline and 2090. Minimum annual rainfall is projected to decline from 521 mm to 431 mm by 2090, a 17 per cent reduction.

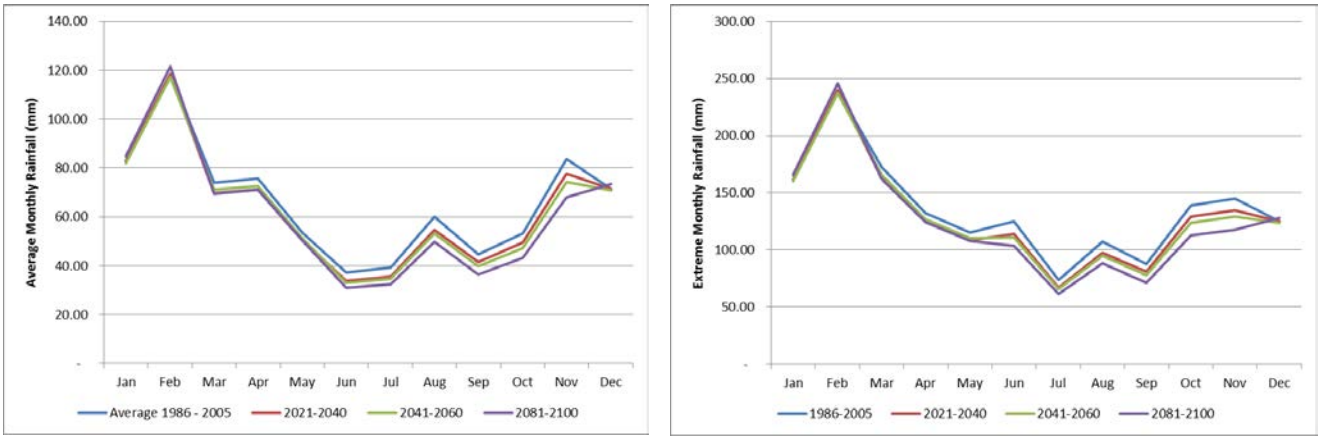
Table 4-1: Annual rainfall projections for western Sydney for 2030, 2050 and 2090, RCP8.5.

	1986-2005	2030 (2021-2040)	2050 2041-2060	2090 (2081-2100
Maximum (mm)	1,352	1,352	1,340	1,387
Mean (mm)	794	752	745	727
Minimum (mm)	521	473	461	431

Based on BoM stations 67033 and 67105 and climate change factors from the Climate Futures Tool (www.climatechangeinaustralia.gov.au).

4.4.2 Monthly rainfall

Seasonal patterns in rainfall are not projected to change much to 2030, although summer rainfall is projected to be slightly greater and winter rainfall slightly less (Figure 4-1). By 2050, winter and spring rainfall are projected to be lower than through the reference period (by approximately 11 per cent). By 2090, rainfall is projected to be lower than during the reference period in all seasons, except autumn. Average autumn, winter and spring and summer rainfall are projected to decline by 6 per cent, 17 per cent and 19 per cent, respectively.



a) Change in average monthly rainfall (mm) **b) Change in extreme monthly rainfall (mm)**

Source: BoM stations 67033 and 67105 and climate change projections from the Climate Futures Tool (www.climatechangeinaustralia.gov.au).

Figure 4-1 Projected changes in average monthly and extreme monthly rainfall totals for western Sydney for 2030, 2050 and 2090, RCP8.5.

4.4.3 Extreme daily rainfall

Extreme values of daily rainfall for western Sydney were typically 150 mm during the climate change reference period. Only during summer and autumn were extreme values of daily rainfall significantly higher than this (with the exception of the wettest day on record). With climate change, extreme daily rainfall values are generally projected to increase (Figure 4-2), in summer in 2090 (2.6 per cent).

Design of the project is to consider very low frequency rainfall events, with average recurrence intervals (ARI) in excess of 1000 years. Atmospheric warming may increase the frequency of the current 1000 year ARI event, as well as increase the rainfall total during the projected 1000 year daily rainfall event with 2050 or 2090 climate.

4.5 Climate change projections for temperature

While climate change projections for temperature are uncertain, there is much greater confidence in these than projections for rainfall. The following sections present projections for change in annual and monthly average temperatures, extreme daily temperatures and heatwaves. Projections are based on changes from the climate change reference period, 1986-2005, using data from BoM stations 67033 and 67105. The projections do not account for any additional urban heat island effects on temperature regime.

4.5.1 Annual temperatures

Projected temperatures in western Sydney (Table 4-2) largely follow the central tendency for GCMs. Average and extreme maximum temperatures are projected to increase 3.8°C and 3.9°C, respectively, under the RCP8.5 scenario. The projected increase in minimum temperatures ranges between 3.8°C and 3.9°C for extreme minimum temperatures.

These projected changes are relative to the 1986-2005 climate change projection reference period, for which extreme maximum temperatures were less than the entire period of record. The highest projected temperature only exceeds the highest recorded temperature for this meteorological station in the projections for 2050 onwards.

Table 4-2: Maximum, average and minimum temperatures (°C) for western Sydney in response to projected climate change.

	1940-2014	1986-2005	2030 RCP8.5	2050 RCP 8.5	2090 RCP8.5
Maximum Tmax	46.4	44.9	46.20	47.00	49.00
Average Tmax	23.5	23.9	25.07	25.87	27.77
Average temperature	17.2	17.5	18.56	19.36	21.36
Average Tmin	10.9	11.0	12.14	12.94	14.94
Minimum Tmin	-8.3	-5.8	-4.80	-4.00	-2.00

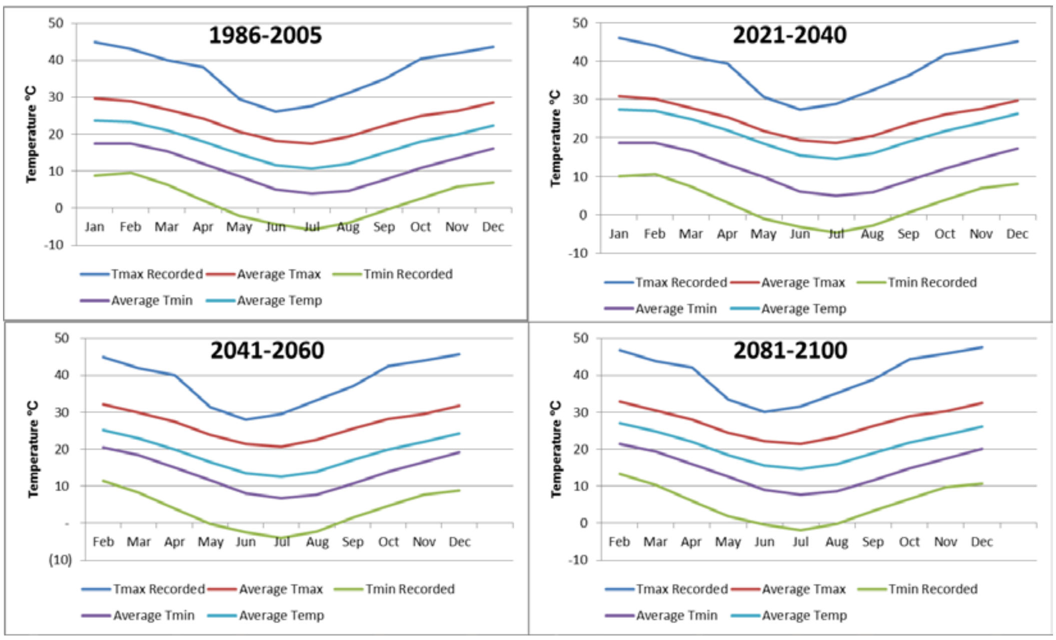
Base data from BoM stations 67033 and 67105. Table includes a comparison of the full period of record, the 1986-2005 climate change projection reference period and RCP8.5 climate change scenarios for 2030 (2021-2040), 2050 (2041-2060) and 2090 (2081-2100). Tmax – maximum temperature; Tmin – minimum temperature.

The historical trend for reduced incidence of extreme cold conditions is projected to continue (Table 4-2) (albeit with more recent slight increase in the number of these days). The number of days with freezing minimum temperatures is projected to reduce, with temperatures being less severe.

4.5.2 Monthly temperatures

Climate change is projected to increase average and extreme temperatures for western Sydney throughout the year (Figure 4-2). Temperatures through the cooler months of winter are projected to increase to a lesser extent than those during other times of year. The range in average temperatures is projected to from 10.4-26.4°C during the climate change reference period to 14.3-30.2°C in 2090.

Days with maximum temperatures above 40°C are projected to increase from October to March, to October to April.



Base data from: BoM stations 67033 and 67105. Figures plot maximum and minimum temperatures recorded in each month (Tmax/Tmin recorded), monthly average temperature and average monthly maximum and minimum temperature (Tmax/Tmin).

Figure 4-2 Monthly temperature profiles for western Sydney: climate change reference period and 2030, 2050 and 2090 RCP8.5 climate change scenarios.

4.5.3 Daily maximum temperatures

Days in which maximum temperatures reach relatively extreme levels (35/40/45°C) in western Sydney are projected to increase in frequency (Table 4-3) in response to climate change. The frequency of days with temperatures exceeding 35°C is projected to more than double relative to the climate change projection reference period by 2090. Days with temperatures exceeding 40°C are projected to experience an almost fivefold increase in frequency. Historically, temperatures exceeding 45°C were only experienced on 1 day per 33 years. Such days are projected to be experienced almost once per year by 2090.

Table 4-3: Frequency of extreme high and low temperatures (°C) for western Sydney in response to projected climate change, RCP8.5 scenario.

	1940-2014	1986-2005	2030 RCP8.5	2050 RCP 8.5	2090 RCP8.5
Days/y ≥45°C	0.03	0.00	0.25	0.40	0.90
Days/y ≥40°C	2.1	2.4	4.0	6.0	10.7
Days/y ≥35°C	14.5	16.3	22.4	27.3	41.7
Days/y ≤2°C	28.5	32.8	19.4	14.8	3.1
Days/y ≤0 °C	10.0	11.8	5.4	3.1	0

Base data from: BoM stations 67033 and 67105.

4.5.4 Daily minimum temperatures

Days with extreme minimum temperatures are projected to decline in frequency over the course of this century under the RCP8.5 scenario (Table 4-3). Freezing days occur at a rate of approximately 12 per year over the reference period, and are projected to decline to zero over the reference period by 2090. Days of frost, with temperatures of 2°C or less, are projected to decline to 3.1 days/y from 28.5 days/y by 2090.

4.5.5 Heatwaves

The frequency and severity of heatwave effects was assessed over the historical record using the method of Nairn and Fawcett (2013; Section 3.4.5). This same approach was used to assess the impact of projected climate change on future heatwave incidence (Table 4-4). While the analysis used the same reference temperatures and excess heat factors, Nairn and Fawcett's methodology accounts for some acclimation to warmer conditions.

Table 4-4: Change in incidence and duration of heatwaves in western Sydney in response to projected climate change, RCP8.5 scenario.

	1940-2014	1986-2005	2030 RCP8.5	2050 RCP 8.5	2090 RCP8.5
Days/y EHF>0	18.4	20.2	35.8	48.2	91.5
Days/y EHF>EHF_{85}	1.6	1.7	2.9	4.7	10.8

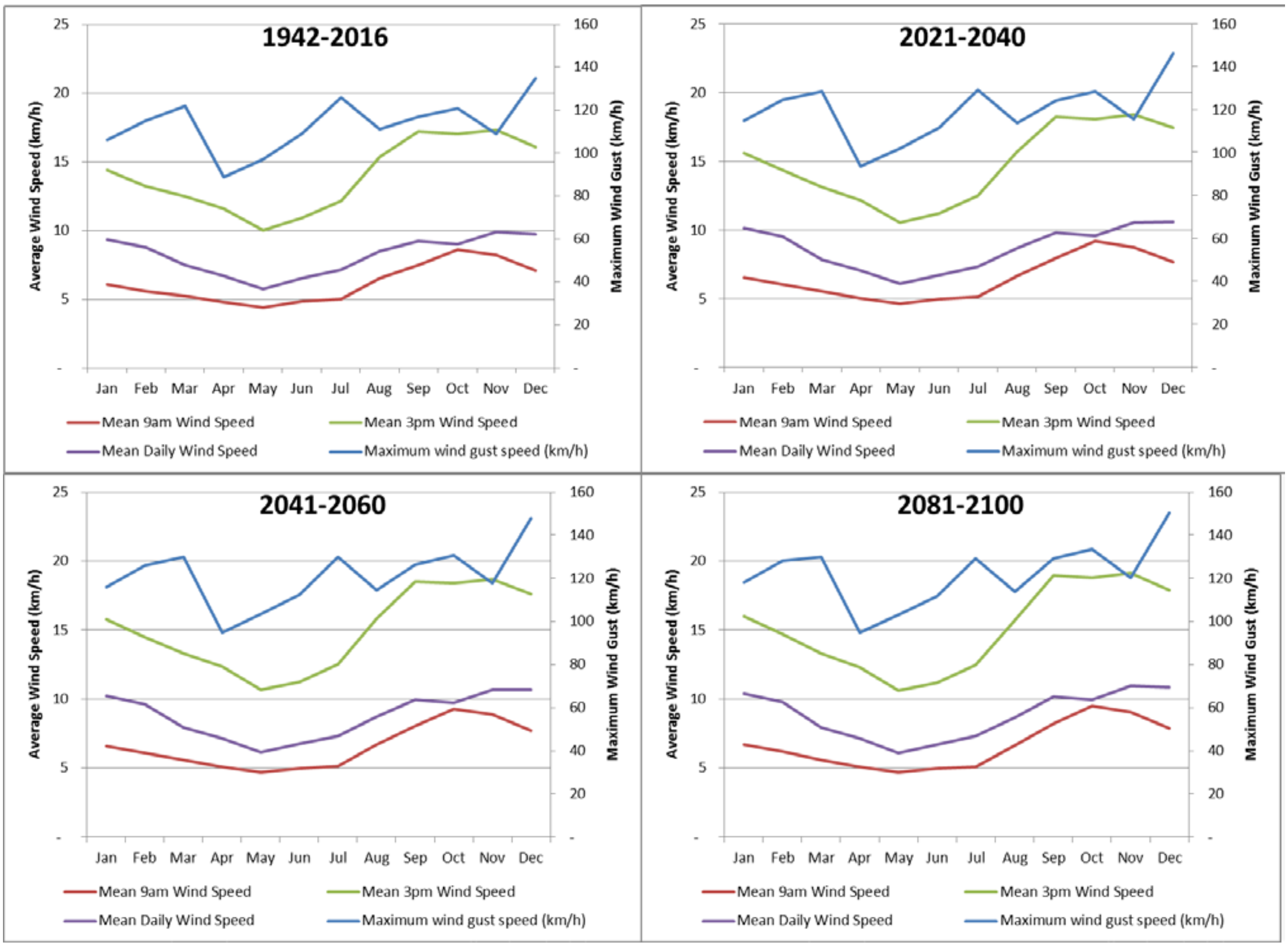
Base data from: BoM stations 67033 and 67105. Analysis approach based on Nairn and Fawcett (2013). EHF (excess heat factor) >0 denotes a heatwave event. EHF>EHF_{85} (85th percentile value of excess heat factor) denotes an extreme heatwave.

The frequency of days with excess heat and severe heatwave conditions is projected to increase more than fourfold between the climate change reference period and 2090 (Table 4-4), with the frequency of such days increasing from 20.2/y to 91.5/y. Severe heatwave days are projected to increase in frequency by a similar order, from 1.6 days/y during the reference period to 10.8 days/y in 2090.

4.6 Climate change projections for wind

Climate change is anticipated to have only marginal impact on average and extreme wind events (Figure 4-3). Average wind speed is projected to decline by up to 5 per cent in all seasons, except winter in 2050 and summer in 2090 under the RCP8.5 scenario, when small increases in wind speed are projected.

The severity of the 1 in 20 year wind gust is projected to decline slightly in summer and autumn throughout the projection period and in winter in 2030 and spring in 2090, under the RCP8.5 scenario.



Base data from: BoM stations 67033 and 67105. Projections based on change from full length of record (1942-2016) rather than the climate change reference period (1986-2005).

Figure 4-3 Projected changes in average wind speed for western Sydney, RCP8.5 scenario.

4.7 Other changes in land and atmospheric conditions

Climate change projections are available from some GCMs for other land-based atmospheric conditions, including: solar radiation, humidity and potential evapotranspiration. This section provides a synopsis of projections which are relevant to the western Sydney region.

4.7.1 Storm systems

Strengthening of the sub-tropical ridge and expansion of the tropical Hadley Cell circulation is projected to continue through the 21st Century (McInnes *et al.* 2015a). This is anticipated to contribute to reductions in storminess and rainfall over southern Australia. The number of extra-tropical cyclones affecting Eastern Australia, including deep low pressure systems in the Southern Ocean and East Coast lows, is projected to decline overall. However, there are suggestions that intense frontal systems affecting south-eastern Australia during summer may increase strongly under some emissions scenarios (McInnes *et al.* 2015a).

4.7.2 Solar radiation

Natural variation in solar radiation is projected to be large compared with any changes resulting from greenhouse gas emissions. Annual average solar radiation is projected to increase in Eastern Australia, although these are anticipated to be small and confined to the latter part of the 21st century (i.e. 1.3 per cent increase at 2090; Kirono and Wilson, 2015). The change will most likely result from increased solar radiation through winter and spring. Changes in radiation are generally inversely correlated with changes in rainfall, with increased radiation occurring when rainfall declines.

4.7.3 Humidity

Relative humidity is projected to decline in inland and southern regions of Australia, where rainfall is projected to decline. Projected changes in humidity are small in 2030 and in 2090 - the median projected change in humidity by 2090 (RCP8.5) is a decline of less than 2 per cent for Eastern Australia (Kirono and Wilson, 2015).

4.7.4 Potential evapotranspiration

It is expected that potential evapotranspiration will increase with temperature and an intensifying hydrological cycle. Climate change projections suggest potential evapotranspiration will increase throughout Australia in all seasons. Increases in the annual potential evapotranspiration are generally projected to be less than 5 per cent by 2030, but may be as much as 10-20 per cent by 2090 (RCP8.5). The extent of change is projected to vary seasonally, with greater percentage changes in autumn and winter, but greater changes in the amount of potential evapotranspiration in summer (Kirono and Wilson, 2015).

4.7.5 Soil moisture

Changes in soil moisture in response to climate change will reflect its projected influence on rainfall and evaporative demand. In southern Australia, soil moisture is projected to decline in all seasons (Mpelasoka *et al.,* 2015), but by a greater extent during winter and spring, when soils are typically more moist. Median soil moisture is projected to decline by up to 13 per cent by 2090 (RCP8.5).

4.7.6 Run-off and groundwater recharge

Groundwater recharge is not specifically addressed by the *Climate change in Australia Technical Report.* However, it can be assumed that since groundwater recharge is influenced by rainfall and evaporation in a similar way to run-off; that it is likely to decline in response to climate change. Depending on location, this may result in lower groundwater levels or pressures.

Projections of changes in run-off are relevant to the project in terms of their potential implications for the availability of potable (and other) water resources. However, reduced average seasonal or annual run-off does not necessarily mean that urban stormwater run-off will decline. The latter is most affected by changes in daily or sub-daily rainfall intensity. Although uncertain, CGM typically project that the intensity of extreme rainfall events will increase.

4.8 Discussion

Western Sydney has a highly variable climate. Annual and season rainfall and temperatures vary over a wide range. The area is periodically subject to extreme weather and climatic events which may disrupt the community, threaten health and safety and damage infrastructure and the environment. Western Sydney's climate is also changing, with signs evident in records of temperature. Those and other changes are projected to continue as increasing atmospheric concentrations of greenhouse gases drive warming and other changes in the climate system.

Over the course of the 21st Century, western Sydney's climate is expected to become:

- *Warmer:* with increased average and extreme high temperatures, but fewer extreme cold temperatures;
- *Drier:* rainfall is projected to decline. Reduced annual rainfall and increased evaporation is anticipated to result in drier soil conditions, less run-off in water supply catchments and reduced average river flows and groundwater recharge;
- *Subject to more extreme weather conditions:* hydrological cycles are projected to intensify with atmospheric warming, leading to more intense extreme rainfall events. Heatwaves will become more frequent, intense and prolonged. While extreme weather conditions may become more extreme, they may become less frequent.

Projected changes in climate over the course of the 21st Century may be disruptive to the operations of the project and users of western Sydney's road network, increase operations and maintenance costs and shorten its operating life. While climate change projections are uncertain, the opportunity exists to assess its implications for the project and to incorporate appropriate, proportional measures to help ensure its resilience under the climate it will experience over its operating life.

5. Climate change risk assessment

This section presents the assessment of risk to the project as a result of climate change. The methodology for conducting this climate change risk assessment has been based on the Australian Standard AS 5334-2013 *Climate change adaptation for settlements and infrastructure – A risk based approach*[3]. The risk assessment is intended to form part of a risk management process which involves communication and consultation with the design team, relevant stakeholders such as Transport for NSW as well as regular monitoring and review of the risk assessment plan as show in Figure 5-1.

The standard follows the International Standard ISO 31000:2009, *Risk management – Principles and guidelines* (adopted in Australian and New Zealand as AS/NZ ISO 31000:2009), which provides a set of internationally endorsed principles and guidance on how organisations can integrate decisions about risks and responses into their existing management and decision-making processes.

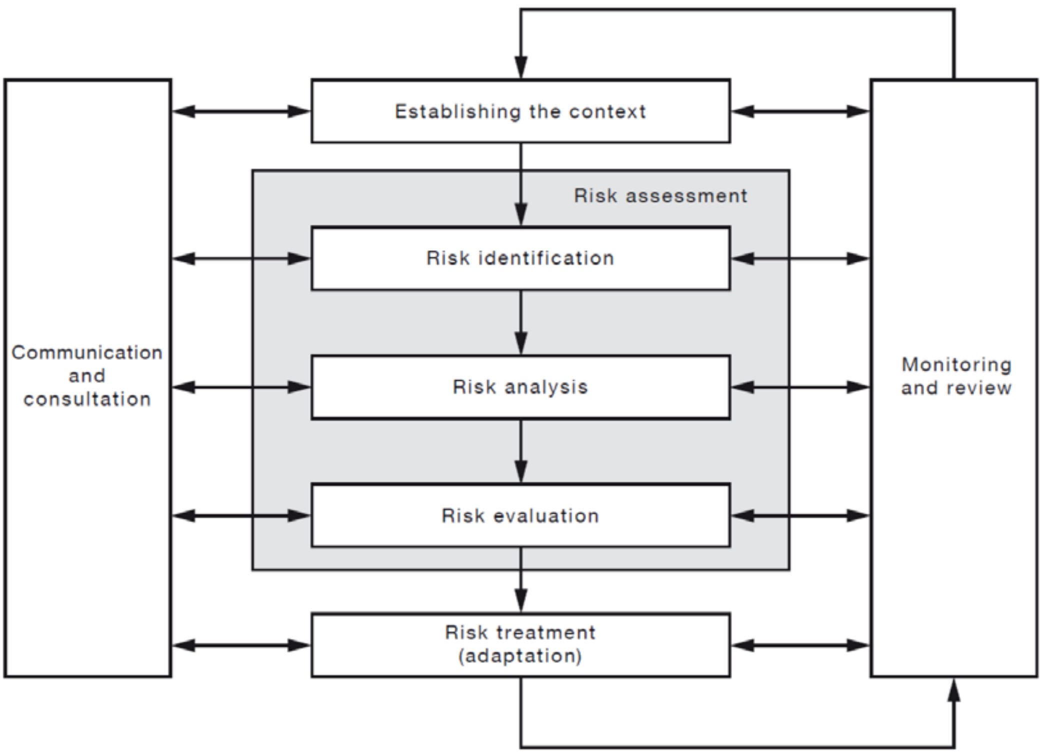


Figure 5-1 Risk Management Process

Source: Reproduced from AS/NZS ISO 31000

5.1 Risk evaluation and approach

Risks to the operation and maintenance of the project that might be influenced by climate change have been identified. The hazard-receptor pathway model has been applied to identify and describe risks. This model is outlined below:

- Hazard – climate or climate-influenced attributes with potential to influence the project's operation and maintenance. Example of hazards specific to the project can be found in Table 5-1.

[3] AS 5334 has superseded Australian Greenhouse Office (AGO) Climate Change Impacts and Risk Management – A Guide for Business and Government as the main Australian climate change adaptation guidance document.

- Receptor – the component of the project's operation and/or maintenance impacted by the hazard. This may also include users of the project and affected elements of the surrounding environment. Key components of the project at risk can be found in Table 5-2.

- Risk Rating – utilising the likelihood (Table A.7-1) and consequence (Table A.7-2) rating system outlined in Appendix A, an assessment of the way hazards influence the project receptors is undertaken and a risk rating awarded (Table A.7-3). The completed assessment is provided in Appendix B.

Within the risk assessment process, the risk resulting from the projected change in climate is assessed, whether this is a newly identified or elevated existing risk. For example, some risks are already present (flooding) but the frequency and intensification of these are projected to change. Other risks (such as migration of pests and weeds) may not be expected to happen in the absence of a changing climate.

5.2 Risk treatment

Risk treatment options have begun to be developed for those risks classified as 'Medium' and above. These treatment options will be further detailed as the design progresses from definition design to detailed design, at which point, detailed modelling and decisions surround design components, will be further developed / incorporated.

5.3 Overview

Climate change is anticipated to have direct and indirect impacts on the project. The types of impacts are relatively well understood, however their severity and extent is uncertain. As such, risks need to be identified and assessed and strategies to treat them developed.

The combined direct and indirect impacts of climate change may contribute to one or more of the following categories:

- Accelerated infrastructure deterioration and increased maintenance requirement
- Safety incidents
- Increased frequency and / or duration of road closure/cancellations
- Adverse road user experience due to climate (not as a result of service disruption)
- Infrastructure loss (total or partial loss as a result of a severe weather event).

This is anticipated to have implications for capital and/or operational expenditure. In catastrophic situations, such as infrastructure failure related to extreme climate events, impacts may include major road accidents or loss of life (although with appropriate risk controls such an event is extremely unlikely).

5.4 Identification of hazards

A hazard is described as the potential for harm. Sources of hazards of relevance to the project include climate phenomena such as flooding and heatwaves. Hazards may occur in isolation or in combination with one another. The confluence of natural events, such as extreme rainfall combined with severe wind, may intensify projected impacts. The influence of climate change on such events is not well understood.

Table 5-1 identifies potential climate change hazards.

Table 5-1: Identified project hazards

Hazard	Description and impact
Temperature and the incidence of heatwave	Increased average temperature and more frequent heatwave events may affect the structural integrity of the road surface, bridges, (and supporting infrastructure (i.e. electronic signals)). It may also lead to higher operational and maintenance costs through more rapid deterioration of infrastructure or disruption of services such as closures and delays.

Hazard	Description and impact
Severity of seasonal drought	Climate change is likely to influence the severity and duration of drought. These changes may affect the geotechnical stability of the land, hence undermining the structural integrity of road infrastructure. Drought may also alter the natural physical surroundings along the project. This is a potential issue for vegetation cover, especially when used for erosion protection.
Rainfall intensity and frequency	Decreased rainfall depth and frequency may result in changes to water table levels, which will affect groundwater flows. Drying of drainage channels may result in weakening which in periods of severe rainfall are eroded more easily.
Severe rainfall events resulting in floods	Excessive rainfall can lead to flash or prolonged flooding (both from excessive stormwater and river flooding). The potential implications include infrastructure damage and/or failure and operational delays. Greater levels of surface water flow during extreme events may cause dangerous driving conditions and instability for embankments and retaining walls along the project.
Frequency and intensity of bushfire	Higher temperatures and changes to rainfall patterns suggest an increase in the frequency of extreme fire weather, which if fires occur, may make their behaviour more difficult to manage. Given its semi-rural location, the project may be directly affected by the impact of bushfire, and indirectly the local air quality may be affected by smoke and dust, along with reduced visibility for drivers.
Rate of annual evaporation	Increased annual evaporation will have an impact on the influence soil wetting and drying cycles, river flooding and fire. Drier climate (warmer, less rain, less humidity and increased evaporation) is associated with reduce road pavement deterioration).
Carbon dioxide concentration in the atmosphere	An increase in concentration of carbon dioxide combined appropriate temperatures and humidity levels, will lead to increased depth of carbonation of concrete, which in turn can increase the likelihood of carbonation induced reinforcement deterioration (CSIRO, 2010). For the project this may involve enhanced deterioration of the reinforced concrete elements and shortening of its operational life.

5.5 Identification of receptors

The potential project infrastructures (receptors) that may be affected by the hazards described above are displayed in Table 5-2.

Table 5-2: Potential impact receptors

Receptor	
	• Roadway and footpaths • Embankments and retaining walls. • Ancillary infrastructure – signals, power • Signage • Lighting • Drainage and culverts
Bridges	• Ramps • Piers and Footings • Bridge Deck and Railings • Drainage
Maintenance Staff	• Maintenance works

Receptor	Receptor components
Electrical supply	• Supply points • Transformers • Back –up generation • Substations
Natural (Urban) Environment	• Natural vegetation and fauna associations

5.6 Identified operational risks

Risk analysis and evaluation was undertaken through desktop assessment, and in liaison with other specialist studies (such as hydrology). The risk assessment involved the following steps:

- Identify the hazard and receptor
- Assess the potential exposure
- Identify existing controls and their effectiveness
- Identify the consequence rating (C1-C6) corresponding to the maximum credible impact across the consequence categories (may be more than one), given the existing controls and their effectiveness
- Identify the likelihood of occurrence of those consequences at that level, taking into account business as usual controls and their effectiveness
- Determine the level of risk based on the intersection of the consequence and likelihood rating
- Determine any action (e.g. risk treatment) and escalation based on the level of risk
- Recommend next steps for detailed design to undertake prior to reconsideration of the level of consequence and likelihood (and therefore residual risk).

The following table presents those results which, following the initial review, presented as ‘Medium’ or higher.

Table 5-3: Risks identified as ‘Medium’ or higher

ID	Risk	Rating	Mitigation measures
3	Increased temperatures and the more frequent incidence and severity of heatwaves. Maintenance activities have to be postponed due to extreme heat. Delay in maintenance activities causes a backlog in work.	Medium	Accept risk and use standard RMS procedures for working in extreme heat.

ID	Risk	Rating	Mitigation measures
9	More severe extreme flood events. Drainage channels and culverts are too small as 100 year ARI storms (the design standard) is more severe as a result of climate change. Road is overtopped with flooding, and standing water in the road causes accidents and severe delays. Damage occurs to roadway requiring immediate rectification which increases maintenance costs.	Medium	Storm water modelling to review climate change projections and flooding for 10 per cent, 20 per cent and 30 per cent increases on standard 100 year ARI event. Scour protection would be provided at inlets and outlets. Further discussion on potential increases in flood risk is provided in the flooding and hydrology working paper.
10	Increase in the frequency and intensity of severe rainfall events. Drainage channels and exits of culverts suffer increased scour as 100 year ARI storms (the design standard) are more severe as a result of climate change Culverts and drainage channels are overwhelmed causing increased flooding on the up flow side of the culverts, and increased scour at the outflows. This results in increased road closures, and increased maintenance / rectification costs. Diverted water may produce increased flooding at existing properties.	Medium	Storm water modelling to review climate change projections and flooding for 10 per cent, 20 per cent and 30 per cent increases on standard 100 year ARI event.
14	More severe fire weather and elevated fire weather conditions. Increased local bushfires cause decreased visibility due to smoke effects Road users suffer reduced visibility due to smoke effects resulting in accidents.	Medium	Accept risk and actively manage through road closures as appropriate.
20	Increased concentration of carbon dioxide in the atmosphere. Carbonation occurs to a greater depth in concrete structures, allowing exposure and degradation of reinforcement. Retaining walls, piers and bridge deck elements are degraded quicker than anticipated shortening their design life. Shorter design life results in greater levels of inspection and maintenance needed, increase asset operational costs.	Medium	Review standards for concrete cover of reinforcement to provide additional coverage as required.

The remaining risks were classified as ‘Low’ or ‘Negligible’. For these risks, no risk treatment is proposed at this stage – although some of the risks will be followed up upon at Detailed Design stage.

The results of the assessment can be found in Appendix B.

6. Mitigation measures

For those risks identified as ‘Medium’ for this project, further information is required for most of the risks before they can be reanalysed and re-evaluated. The current design stage does not contain sufficient detail to close these out whilst the major design features are being finalised and as such the risk register will need to be revisited a number of times to both add in new risks, as well as reanalyse and re-evaluate current risks.

Generally, the mitigation measures identified for the Greenhouse Gas Assessment carried out for the project should be implemented to reduce the impact of climate change risks.

7. References

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Appendix A. Risk Assessment Tables

Table A.7-1 : Likelihood Criteria

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

Table A.7-2 : Consequence Criteria

CONSEQUENCE CRITERIA												
		IMPACTS ON PROJECT OBJECTIVES										
		TECHNICAL PERFORMANCE										
Consequence Rating		Time		Cost		Safety		Environment Implementation Operation	Traffic Flow Peak Hour	Local Traffic	Community Attitude	Fit for Purpose Defects Accidents Maintenance Costs
		Development	Implementation	Development	Implementation	Implementation	Operation					
CONSEQUENCE	Extreme	YEAR	MONTHS	$ (25% o/c)	$ (10% o/c)	WCL: >$250,000 Death/Perm. loss of physical/mental amenity	Multiple WCL: > $250,000 Death/Per. loss of physical/mental amenity	Major environmental damage &/or Delay due to Legal Finding in Land & Environment	No Improvement	Severe Disruption	Severe Community Protests	Functional Failure
	High	MONTHS	MONTHS	$ (15% o/c)	$ (7% o/c)	WCL: $10,001-250,000 Lost time =>5 days	WCL: >$250,000 Death/Perm. loss of physical/mental amenity	Serious environmental damage &/or Delay due to Public Enquiry. EPA Major Notice	Marginal Improvement	Disruption	Community Protests	Serious Functional Failure
	Medium	MONTHS	MONTHS	$ (7.5% o/c)	$ (4% o/c)	WCL: $1,001-10,000 Lost time 1-4 days	WCL: $10,001-250,000 Lost time =>5 days	Environmental damage & / or EPA Infringement Notice			Daily Complaints	Minor Functional Failure
	Low	MONTHS	WEEKS	$ (1 % o/c)	$ (1% o/c)	WCL: $251-1,000 Lost time =>1day	WCL: $1,001-10,000 Lost time 1-4 days	Minor environmental damage &/or Minor EPA Infringement Notices. Writen Community comments	km/hr Give a value		Complaints	
	Negligible	WEEKS	NIL	$ (0.1% o/c)	$ (0.1% o/c)	WCL: $1-250 First Aid treatment (no lost time)	WCL: $251-1,000 Lost time =>1day	Minor repairable environmental damage Verbal Community Comment	km/hr Give a value		Negligible Complaints	

O/C – Overall Construction Cost
WCL – Worker's Compensation Liability

Table A.7-3 : Risk Ranking matrix

Likelihood		Risk levels				
	Extreme	M	H	E	E	E
	High	L	M	H	E	E
	Medium	N	L	M	H	E
	Low	N	N	L	M	H
	Negligible	N	N	N	L	M
		Negligible	**Low**	**Medium**	**High**	**Extreme**
		Consequences				

Appendix B. Risk Assessment