16. Climate change adaptation

The impacts of climate change (such as an increase in extreme weather events or increasing average temperatures) can lead to risks to the development of projects. Risks can include flooding or reduced life-cycles of materials used in during construction. This chapter explores the potential impact of climate change on the future operation of the project, and on the project infrastructure.

DGRs	Where addressed in the EA
Design, Sustainability and Amenity — including but not limited to:	
▪ stop design and corridor landscaping, relationship to surrounding land uses and built form and the visual impacts of the project from surrounding areas	Chapter 14
▪ safety and security of passengers, GreenWay shared path users and the wider community	Chapter 14
▪ privacy and amenity impacts from stops, the light rail corridor and the GreenWay shared path	Chapter 14
▪ energy demand, efficiency and climate change adaptation measures.	Chapters 15 and 16

16.1 Background

Some level of climate change will occur irrespective of efforts to reduce greenhouse gas (GHG) emissions. Adaptation is the key policy approach that has been adopted to maximise the opportunities that climate change will present while minimising its costs. The NSW Government is developing a draft *Climate Change Action Plan,* which will be the principal NSW document for articulating its position in climate change programs for the next five years. The plan will complement and replace the work of the 2005 *Greenhouse Action Plan*. The *Climate Change Action Plan* will establish a policy framework for NSW based on emissions reduction, climate change adaptation and low-carbon economic activity. The NSW Government intends to focus on the adaptation aspect to unavoidable climate change.

In 2010, the NSW Government also released its policy document, *State Plan – Investing in a Better Future,* which established priorities in NSW for the next 10 years. This document sets out the long-term key issues for NSW, which include better transport, improved health in the communities, and a green state among others. While not explicitly discussed, climate change risk management and the uptake of adaptation measures clearly contribute to reaching some of the stated goals in the ‘Green State’ Chapter of this policy document. These include securing sustainable supplies of water and using water more wisely, as well as protecting biodiversity and various water bodies.

The key document for assessing climate change risk is the Commonwealth Government’s publication ‘*Climate Change Impacts and Risk Management: A Guide for Business and Government’* (Australian Greenhouse Office 2006), which sets out a framework for organisations to integrate climate change impacts into risk management and other strategic planning activities in public and private sector organisations.

16.2 Assessment approach

Climate change has been assessed in relation to air temperatures, rainfall, humidity and other climatic variables and their potential to affect the project.

Historic weather patterns were determined through analysis of the Australian Bureau of Meteorology (BoM) monitoring station at Observatory Hill. The data recorded were used to determine current climatic trends.

Climate change projections were taken largely from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Commonwealth Bureau of Meteorology publication *Climate Change in Australia — Technical Report 2007*, which provides regional projections consistent with the Intergovernmental Panel on Climate Change's (IPCC) *Fourth Assessment Report 200*7. Projections for rainfall intensities and extreme temperatures, which are of particular relevance to the SLRE, were obtained from consultations with CSIRO researchers, while projections for other climatic variables representative of the study area were extrapolated from various reports and studies.

16.2.1 Methodology

Scenarios

The IPCC has developed a set of scenarios to explore potential future climate change using complex, computer-based Global Climate Models. The scenarios differ in their assumptions about future changes in population, economic development, energy technologies and other factors, resulting in growing differences in the greenhouse gas (GHG) concentrations in the atmosphere and hence the degree of projected climate change.

There are over 30 IPCC scenarios that have been developed to estimate the characteristics of future climatic conditions. The scenarios address the complexity and uncertainty of climatic systems and represent the range of driving forces and emissions. These scenarios are based on assessment modelling and a variety of literature. The emission scenarios are converted to atmospheric concentrations using carbon cycle models. Four storylines (A1, A2, B1, and B2) were developed to describe consistently the relationships between emission driving forces and their evolution; under these storylines are six scenario groups, which represent different energy technology developments:

A1F1 — fossil fuel intensive, i.e. rapid economic growth

A1B — balanced, i.e. not relying too heavily on one particular energy source

B1 — same as A1 storyline but with emphasis on service and information economy, reductions in materials intensity

A2 — self-reliance and preservation of local identities, i.e. very heterogeneous world

A1T — predominantly non-fossil fuel

B2 — local solutions to sustainability issues, intermediate levels of economic growth.

Typically, the first four scenarios are the most used ones.

As the light rail extension is anticipated to have a long design life, GHG emissions are examined for 2030 and 2070. The concentration scenarios for carbon dioxide (CO_2) are relatively similar up to 2030, but diverge greatly past that point. To reflect the possible range of climate change, projections for various scenarios — high emissions scenario (‘High’), medium emissions scenario (‘Medium’) and a low emissions scenario (‘Low’) — are used to assess potential climate change impacts. Although all scenarios are equally plausible, it should be noted that since 2000, observed global CO_2 emissions have generally been tracking at the most pessimistic levels of the most intense scenario (A1F1) (Canadell et al. 2007). A new set of scenarios will be developed at the next IPCC review to be finalised in 2014 and it is reasonable to assume that scenario values will generally be revised to reflect more severe climatic conditions.

Risk assessment

Given the projections in the project area to 2030 and 2070, the climate change-related risks to the project are identified and assessed to determine a priority list for risk mitigation. The risk assessment generally only considers the risks of direct impacts on the project, which can occur through extreme weather events, accelerated degradation of assets and resource demand pressures. The risk assessment process followed is consistent with the *Climate Change Impacts and Risk Management: A Guide for Business and Government*, which in turn is consistent with the *Australian and New Zealand Standard for Risk Management (AS/NZS 4360-2004)*.

Vulnerability

The project’s vulnerability to climate change would be determined by its exposure to the changing climate, its sensitivity to those changes and the adaptive capacity of the project’s operator. Light rail infrastructure would be exposed to potential risks of inundation, wind hazards and temperature. There would be localised risk of flooding of the alignment and the GreenWay shared path from the local catchment/Hawthorne Canal flow near Marion stop.The project’s exposure is related to its location and its various components (track, stops, GreenWay shared path, etc.). Its sensitivity reflects the degree to which individual components, and the project as a whole, are affected (either adversely or beneficially) by changes in climatic variables, including means, extremes and variability (Australian Greenhouse Office 2006). Exposure and sensitivity define potential vulnerability, but this can be mitigated by appropriate adaptation responses.

Risk identification

Throughout this study, a range of climate change-related risks the project is potentially subject to were identified, noting that the project comprises a variety of infrastructure, including rail track, stops, signalling and communication equipment, lighting and the GreenWay shared path.

There are two types of risks:

- risks of direct climate change-related impacts on the light rail extension and its ancillary infrastructure nearby
- risks of indirect impacts arising from impacts on resources, supplies and markets that the project would rely upon.

This exercise focused on the direct climate change-related risks, and of these risks only obvious and potentially significant risks have been identified.

Risk analysis

The risk scenarios associated with each of the identified risks were analysed to determine their consequences (should the risk eventuate) (refer to Table 16.2 for the consequence scale), their likelihood (of the risk happening during the project's planned operational life) (refer to Table 16.1 for the likelihood scale) and their existing controls (measures in place to treat the risk or mitigate its impacts). Consequences were assigned by referring to the Consequences Scale in *Table 10 in Climate Change Impacts & Risk Management: A Guide for Business and Government* (Australian Greenhouse Office 2006), which was developed for commercial businesses. Its criteria for success include shareholder value, growth, supply chain, human resources and compliance. The likelihood of each risk scenario happening was assigned with reference to Australian Greenhouse Office (2006), but adjusted for the project life. Risk controls were based on current light rail practice.

Additionally, given the imminent timing of construction, climate change impacts on construction are not considered to be significant during the construction phase of the project.

Table 16.1 Likelihood scale

Likelihood	Recurrent risks	Single events
Almost certain	could occur several times per year	more than 50% probability per year
Likely	may occur once per year	as likely as not — 50/50 chance
Possible	may occur once in 10 years	less than 50%, but still quite high
Unlikely	may occur once in 10 to 25 years	low probability, but more than zero
Rare	unlikely during next 25 years	negligible, probability close to zero

Table 16.2 Consequence scale

Consequence Level	Financial — economic	Service Delivery	Governance and reputation	Social-environmental
	Success factors			
Catastrophic	Significantly high financial losses of greater than 10% of operating budget.	Permanent damage and/or loss of infrastructure	Major policy shifts and changes to legislative requirements	Multiple fatalities or significant irreversible effects Very serious long-term environmental impairment of ecosystem
Major	Major financial losses of 5-10% of operating budget	Extensive infrastructure damage requiring extensive repair	Public administration would struggle to remain effective Serious public or media outcry (international coverage)	Major damage to structures/items of cultural significance Single fatality and/or severe irreversible disability Serious long-term environmental impairment of ecosystem
Moderate	Significant financial losses of 2-5% of operating budget	Significant infrastructure damage and loss of service Damage recoverable by maintenance and minor repair	Public administration would be under severe pressure Significant adverse national media/public/NGO attention	Significant damage to structures/ items of cultural significance Moderate irreversible disability or impairment Serious medium-term environmental effects
Low	Additional operational costs. Financial losses of 1% of operating budget	Local infrastructure service disruption; no permanent damage. Some minor restoration work required	General concerns raised over current public administration Attention from media and/or heightened concern by local community; criticism from NGOs	Damage to items of cultural significance Some disability requiring hospitalisation Moderate short-term effects but not affecting ecosystem functions
Minimal	Financial losses of less than 0.1% of operating budget	No infrastructure damage	No changes to management required Minor, adverse local public or media attention or complaints	Minor medium-term impacts on local population Mostly repairable No medical treatment required

Table adapted with reference to:

- HB 436:2004 – Risk Assessment Guidelines. Companion to AS/NZS4360:2004 (Table 6.1)
- CSIRO 2006, *Infrastructure and Climate Change Risk Assessment for Victoria*,
- Department of the Environment and Heritage 2006, *Climate Change Impacts and Risk Assessment: A Guide to Business and Government*.

Risk assessment

To assess the risk, the risk scenarios were ranked by assigning each a rating based on their combination of consequence and likelihood. Table 16.3 provides the Risk Rating Matrix used, which was adapted from Table 12 in *Climate Change Impacts & Risk Management: A Guide for Business and Government* (Australian Greenhouse Office 2006*)* by placing greater importance on consequences.

Table 16.3 Priority matrix

Risk Rating Matrix					
	Consequences				
Likelihood	**Insignificant**	**Minor**	**Moderate**	**Major**	**Catastrophic**
Almost certain	Medium-9	Medium-6	High-4	Extreme-3	Extreme-1
Likely	Low-5	Medium-7	High-5	High-2	Extreme-2
Possible	Low-6	Medium-8	Medium-4	High-3	High-1
Unlikely	Low-7	Low-3	Medium-5	Medium-3	Medium-1
Rare	Low-8	Low-4	Low-2	Low-1	Medium-2

Risk prioritisation

Interim risk ratings were determined, sorted and ordered, with an aggregate review done to ensure the relative ratings were reasonable, consistent and appropriate. Risk ratings were adjusted accordingly, with final risk ratings prioritised and listed. Column 4 of Table 16.5 shows the adopted risk ratings.

16.3 Existing environment

The closest meteorological station to the project area is at Sydney Observatory Hill, approximately 5 to 10 kilometres north-east of the project location. Mean daily temperatures range from 16.3°C in July to 25.9°C in January. In December and January, maximum temperatures exceed 30°C on 10% of days, with a maximum recorded temperature since 1859 of 45.3°C. Mean monthly rainfalls vary from a high of 130.7 mm in June to a low of 69.1 mm in September. The average annual rainfall is 1212.8 mm.

16.4 Projected climate changes

The Earth's climate can be projected with reasonable confidence over the next few decades to a plausible mid-century time horizon because climate change would be largely determined by historical emissions of greenhouse gases. Beyond the mid century point, however, there is much less certainty, and to address the uncertainty related to future emissions growth, the IPCC developed its four storylines (A1, A2, B1, and B2), which discuss different development patterns.

This assessment is based largely on findings of the publication *The impacts of climate change on the biophysical environment of New South Wales* (Department of Environment, Climate Change and Water NSW 2010) and focuses on just one of these storylines (A2). Essentially Department of Environment, Climate Change and Water (DECCW) refined regional climate projections for NSW based on the models used for the IPCC's *Fourth Assessment Report* (AR4) and the CSIRO and Bureau of Meteorology (BoM) publication *Climate Change in Australia — Technical Report 2007.*

Table 16.4 presents the climate change projections for the project area throughout the century under varying emissions scenarios. The middle column presents DECCW's summary for expected changes to temperature, rainfall, and evaporation between now and the year 2050.

Table 16.4 Climate change projections

Variable	Units	Current	2030 Medium (A1B)	2050 (DECCW)	2070 High (A1FI)	Notes
Mean sea level rise	Projected 50th percentile mean sea level rise (since 1990)		13.9 cm		36.8 cm	1
Average annual temperature	°C change		+0.9°C (0.6 to 1.3)	+1.5°C to +3°C	+3°C (2.1 to 4.3)	2
Extreme temperature	number of days above 40°C per year	0.3	0.6	+1.5°C to +3°C	1.7	3
	number of runs of days (3-5) above 35°C per year	3.6	4.4		8.6	
Rainfall — average annual	% change	-	-3% (-9% to +3%)	10–50% summer increase 10–20% winter increase NB: climate models find coastal patterns difficult to predict	-8% (-25% to +10%)	2
Wind speed	% change in 99th percentile annual daily wind speed	-	-0.71% (-1.81% to +0.62%)	-	-3.27% (-8.35% to +2.86%)	3
Relative humidity	% change	-	-0.4% (-1.3% to +0.4%)	-	-1.2% (-4.0% to +1.3%)	2
Solar radiation	% change in means	-	+0.3% (-1.0% to +1.9%)	-	+0.9% (-3.2% to +6.0%)	2
Potential evaporation	% change	-	+3.0% (+2 to +5)	-	+9.0% (+5 to +15)	2

Variable	Units	Current	2030 Medium (A2)		2050 (DECCW)	2070 Medium (A2)		Notes
Extreme rainfall	% change in 5 year – 2 hour storm rainfall intensities	-	+4% (-14 to +15)		-	+13% (-9 to +45)		4
	% change in 100 year – 2 hour storm rainfall intensities	-	+5% (-38 to +26)		-	+13% (-26 to +49)		
Variable	**Units**					**2050 Medium**		**Notes**
			4 cm hail or greater	**6 cm hail or greater**		**8cm hail or greater**	**10 cm hail or greater**	
Hail	Average recurrence interval (ARI) of hailstorms (relative to 1991)	-	1.2 years (currently 1.4 years)	5 years (currently 8 years)	-	19 years (currently 28 years)	28 years (currently 51 years)	5
Variable	**Units**		**2020**			**2050**		**Notes**
			Low	**High**		**Low**	**High**	
Bush fire weather	number of days per year with 'very high' fire weather (FFDI > 25)	7.6	7.8 (2.6% increase)	8.3 (9.2% increase)	-	8 (5.3% increase)	9.8 (28.9% increase)	6
	number of days per year with 'extreme' fire weather (FFDI > 50)	1.2	1.3 (8.3% increase)	1.5 (25% increase)	-	1.3 (8.3% increase)	1.8 (50% increase)	

Notes:
1. www.cmar.csiro.au/sealevels/sl_proj_regional.html.
2. CSIRO 2007, *Climate Change in Australia — Technical Report 2007,* CSIRO. Table B13 for Sydney. Mean values shown, with 10th and 90th percentile values also shown in brackets to indicate range of projections
3. Extreme temperature data provided by CSIRO (2010).
4. Abbs, D & T Rafter, November 2008, 'Impact of Climatic Variability and Climate Change on Rainfall Extremes in Western Sydney and Surrounding Areas: Component 4 — Dynamical Downscaling', Figures 15–18 (LGA range in brackets). Uses A2 emissions scenario.
5. Leslie, M, Leplastrier, M, and Buckley, B 2008, 'Estimating future trends in severe hailstorms over the Sydney Basin: A climate modelling study', *Atmospheric Research* 87, pp. 37–51, Elsevier.
6. Lucas et al. 2007, *Bushfire Weather in South East Australia: Recent Trends and Projected Climate Change Impacts*, Bushfire CRC and CSIRO (Used Sydney Airport)

Higher extreme temperatures

Projections show the project area is expected to become warmer, with more hot days and fewer cold nights. The project area experiences on average 0.3 days over 40°C a year. This is expected to increase to 0.6 days by 2030, and to 1.7 days by 2070. In real terms, this means that currently one day every three years is over 40°C, while by 2030 this is expected to be at least two days every three years, As a result, energy demand for cooling in summer will increase markedly, although energy demand for heating in winter will decrease due to the expected warmer nights. Buildings, roads and other assets will deteriorate more quickly, increasing their life-cycle costs. Consequently, where sudden spells of hot days occur, light rail track could experience high compression, thereby leading to an increasing potential for misalignment. There would also be increased pressure on social amenities, for example, if there is insufficient sheltering provided at the various stops. Where air-conditioning systems are in operation, their operational thresholds will be more regularly reached, because at 40°C they begin to lose efficiencies and generally shut down at 55°C.

Increased rainfall intensities

The project area is expected to experience an increase in the severity of short duration storms, which cause the most severe flooding. In the more frequent flood events, such as the 5 year storm, the project area is projected to experience a minor increase of 4% in rainfall intensity in the 2 hour storm by 2030. By 2070 there are projected substantial increases of 13% in 2 hour/5 year rainfall intensities in the project area.

However, in larger, less frequent storms that cause significant flooding in the project area, such as the 100 year event, an overall increase of 5% in the rainfall intensity in the 2 hour storm is projected by 2030, and an increase of 13% is expected by 2070.

It is important to note that even a modest increase in rainfall intensity can have a significant impact on the frequency by which a particular flood event is experienced. McLuckie et al. (2006) showed that a 10% increase in rainfall intensity reduces the ARI of a 20-year event to 13 years, and a 100 year event to 50 years.

The potential impacts of flooding on the project are discussed in more detail in Section 17.3.

Reduced average annual rainfall

Average annual rainfall in the project area is expected to decrease. The Sydney region is expected to experience a 3% reduction in average annual rainfall by 2030 and an 8% reduction by 2070. Sydney's mains water supply is likely to come under increasing stress as population growth and environmental flow requirements increase the demand for water, whilst reduced annual rainfalls and increased evaporation suggests less run-off into rivers and water storages. A recent study of likely changes in stream flow under climate change suggests that by 2030 there could be 5% less run-off into Sydney's water storages (Vace et al. 2008).The combined effects of reduced rain, increased average temperatures and an increase in extreme rainfall events could lead to a decrease in soil moisture. This in turn would contribute to subsidence of the ground surfaces, which would affect light rail infrastructure, particularly where such infrastructure has been laid on clay soils.

The soil landscape of the project is discussed in more detail in Section 17.4.

Increased bushfire risk

With decreased rainfall and higher temperatures, the risk of fires will present where there is dense vegetation. The project area now experiences 7.6 days of 'very high' fire danger a year. This is set to increase to between 7.8 and 8.3 days by 2020, and to between 8 and 9.8 days by 2050, while days of 'extreme' fire danger are projected to increase from 1.2 days a year, to between 1.3 and 1.5 days for 2020, and between 1.3 and 1.8 days for 2050.

More severe storms

Climate change is expected to increase the moisture content and energy in the atmosphere, resulting in more severe storms — wind, hail and lightning — with greater potential to cause damages. However, because such storms occur in much finer time and spatial scales than the resolution of global climate models, the degree of change in storm severity cannot be quantified with any certainty.

Sea Level Rise

Sea levels along the NSW coast are projected to rise by 14 cm by 2030, and 37 cm by 2070 relative to 1990 sea levels. NSW Government policy specifies sea level rise planning benchmarks of an increase above 1990 mean sea levels of 40 cm by 2050 and 90 cm by 2100, which Leichhardt Council has acknowledged. The project area will therefore need to consider the potential for increased flooding along its tidal waterways as a result of higher sea levels. A study done in the LGA states that properties located along the foreshore of the Leichhardt LGA would have to account for elevated water levels in Port Jackson that occur during severe ocean storms, generally from the east-north-east to south-south-east sector, not from westerly winds. Those high water levels may be accompanied by local sea wave activity that then causes wave set-up and run-up; though wave set-up will be minimal because wave periods will be very short. However, the highest storm tide levels in the Leichhardt area will occur during storms that have north-east to south-west sector winds — not northerly or westerly winds.

Therefore, the joint occurrence of the highest water levels and highest local wind-generated waves will be very rare on the westward and northward facing shorelines of the study area, which comprises the entire foreshore connection of the Leichhardt Council LGA to Sydney Harbour and the Parramatta River (Estuarine Planning Levels Study).

It is also useful to discuss the influence of king tides, which are usually referred to as any high tides well above the average high tides. The highest spring tides occur in the winter and summer months. The highest of each of these periods are the king tides. Apart from the astronomical factors, tides are modified by many other non-astronomical influences, such as the shape and depth of oceans, ocean currents, and the weather. The combination of factors influencing local tides is complex and varies greatly from area to area. As a result, there is considerable variation in the tidal range around Australia. For example, the tide range on the West Australian coastline varies from approximately 12 metres at Collier Bay in the north to about 0.7 metres in Fremantle. It is important to note that tidal range is not affected by climate change; however, the absolute levels of all tides will increase as a result of sea level rise, and as such the risk of flooding and storm surge as a result of king tides will increase.

More intense hailstorms

The project area can expect much more damaging hailstorms by 2050. Under a medium emissions scenario, hailstorms producing hailstones greater than 10 centimetres in diameter will occur once every 28 years, compared to the current 51 years. Compared to other natural hazards, damaging hailstorms occur relatively frequently in urban areas in Australia. A useful way of assessing this impact is to examine the Insurance Council of Australia's natural disaster event list. An important feature is that it itemises the cost of damage to motor vehicles as well as commercial and domestic buildings and contents.

In discussing the exposure to hail impacts, it is interesting to note that to arrive at the number of vehicles exposed to hail, the number of vehicles located in storm-affected areas must be adjusted by a factor representing the proportion of vehicles under shelter in that area. This 'shelter factor' will also vary temporally and spatially. On a Statistical Local Area basis, an analysis of the proportion of vehicles parked on the street after their journey to home shows that Leichhardt is at the top of the list with 78% (Leigh 2007). Exposures to this hazard would include light rail staff, commuters who park their vehicles within the Leichhardt area and potential damage to light rail vehicles.

16.5 Potential climate change risk scenarios

Potential climate change risk scenarios for the project are presented in Table 16.5, which explains the:

- list of possible climate change risks to the project
- an initial assessment of each risk's priority
- suggested analysis of risk treatment options
- possible treatments as part of key adaptation measures.

Table 16.5 Risk assessment of climate change scenarios

IDENTIFICATION			ASSESSMENT	ANALYSIS — SUGGESTED DESIGN RESPONSE	ADAPTATION MEASURE
Climatic variable(s)	**Risk name**	**Locations**	**Initial risk priority**	**Risk treatment analysis**	**Possible treatment**
Increased solar radiation of at least 0.3% of current levels and more frequent runs of hot days above 35°C (4.4 compared to 3.6 currently)	Accelerated degradation of external materials at surface Increased risk of track buckling due to heat impacts	All locations with surface materials present	Low	Identify and assess possible use of external materials utilised in hotter Australian regions and even other global areas.	1) Ensure durable materials are used to enhance coping capacity and tolerance to exposure of 100% increase in number of days expected to have temperatures greater than above 40°C by 2030. 2) Review maintenance regimes to accommodate acceleration in the degradation of materials.
More frequent and severe storms (especially wind and lightning effects)	Damage to overhead power lines and signals.	All locations with above-ground and exposed power lines/signals and other infrastructure	Medium	Assess resilience of overhead power lines to projected increases in extreme wind gusts.	1) Current provision for design of structures under wind action (AS/NZS 1170.2:2002) has been developed on the basis of historical climate data. Such data has not indicated any sufficient evidence of trends in wind speeds due to climate change. Treatment is therefore to ensure adherence to current specifications within Standard (e.g. 38 m/s for 100 ARI). 2) Review maintenance regimes to accommodate acceleration in the aftermath of extreme wind events. For example, anecdotal evidence suggests that 20% increase in combined thunderstorm and synoptic winds on base case of 100 year ARI (38 m/s) shows wind speed results of 45–46 m/s; at these speeds, OHW systems would not collapse but would be compromised in their positioning by swaying past design thresholds.

IDENTIFICATION			ASSESSMENT	ANALYSIS — SUGGESTED DESIGN RESPONSE	ADAPTATION MEASURE
Climatic variable(s)	**Risk name**	**Locations**	**Initial risk priority**	**Risk treatment analysis**	**Possible treatment**
Increased rainfall intensities	Exposure to stormwater flooding of Hawthorne Canal from increased intensities of 5 year-2 hour storm rainfall intensities (mean projection of a 4% increase in intensities in 2030 from current levels) on the stop, railway track, and the tunnel under the City West Link may lead to: ▪ flooded track, with light rail vehicles stranded and suspended services ▪ foundation instability (washout of ballast and sub grade failure) ▪ traction problems ▪ signals and communications damage ▪ delay to services due to - speed restrictions (flood warnings, engineering solutions). ▪ localised risk of flooding the alignment and the GreenWay shared path from local catchment/Hawthorne Canal flow near Marion stop for the 100 year ARI event.	Surcharges in local drainage systems and overtopping of Hawthorne Canal; specific locations identified as vulnerable to flood risk are: 1) Leichhardt-to-Lilyfield: part of the alignment in this area is flooded at the 5 year ARI event and upwards; however, the flood hazards (depth and velocity) are low in this area 2) Lewisham West: 80 metres of the alignment directly next to the flour mill building is at risk of flooding for the 20 year ARI event and upwards.	Low	Consider risks and recommendations of flood study at detailed design stage.	▪ Raise entry thresholds above flood level plus freeboard. Alternatively, lower threshold and install sump and pump out systems. ▪ Increased passenger protection on platforms in the form of canopy covering stop lengths. This would also provide shading from more sun, as commuters will generally be facing eastwards in the morning hours. ▪ Provide allowance for increased rainfall intensity associated with climate change in drainage system design. ▪ Providing flood protection to the alignment in the form of raised bunds or barriers may not be feasible, as this may exacerbate flooding to adjacent land and properties by displacing floodwater that would currently be stored within the rail corridor. ▪ Mitigation measures for GreenWay are limited in practicality. However, the path can be designed to resist erosion during flood events; GreenWay shared path can also be closed off during stormwater flooding conditions

IDENTIFICATION			ASSESSMENT	ANALYSIS — SUGGESTED DESIGN RESPONSE	ADAPTATION MEASURE
Climatic variable(s)	**Risk name**	**Locations**	**Initial risk priority**	**Risk treatment analysis**	**Possible treatment**
Increased intensity of hailstorms	Impacts on passenger safety from at least a 4% increase in average recurrence interval (ARI) of hail-storms causing damage to light rail vehicles and rail infrastructure.	All locations	Low	Review existing insurance policies and assess coverage for storm events; current policies may not cover hailstorms.	1) Ensure safety critical equipment is designed to be foolproof. 2) Continuously review insurance coverage to maintain cover for hailstorms.
Sea level rise and increased storm surge	Seawater would flood the GreenWay, alignment, stations, and infrastructure. This may lead to: ▪ flooded track, with light rail vehicles stranded and suspended services ▪ foundation instability (washout of ballast and sub grade failure) ▪ traction problems ▪ signals and communications damage ▪ delay to services due to speed restrictions (flood warnings, engineering solutions) ▪ track circuit failure due to salt spray ▪ inundation of GreenWay next to Hawthorne Canal.	Increased tidal flood risk to the GreenWay adjacent to Hawthorne Canal and east of Hawthorne Station: most of the GreenWay length the ground levels are around 2 mAHD, which is below the 100 year ARI still water tidal surge level of 2.4 mAHD, with allowance for 0.9 m of sea level rise. Foreshore would be vulnerable to wave overtopping. Local stormwater systems that outlet to Lower Parramatta River would be affected.	Medium	Consider risks and recommendations of flood study for Hawthorne Canal at detailed design stage. During detailed design consider that positioning of the GreenWay midway up batters will require drainage treatments, without creating scour problems on the batters. Special consideration must be given to the design of the new Hawthorne Canal bridge to ensure the new bridge does not affect upstream flood levels. The bridge will be located in a tidal section of the canal, so rising sea levels would result in higher flood levels at this location. Modelling the canal would confirm the bridge levels and configuration during the detailed design stage.	Most feasible mitigation measures are to evacuate people at risk during floods and to close areas subject to flooding.

IDENTIFICATION			ASSESSMENT	ANALYSIS — SUGGESTED DESIGN RESPONSE	ADAPTATION MEASURE
Climatic variable(s)	**Risk name**	**Locations**	**Initial risk priority**	**Risk treatment analysis**	**Possible treatment**
Reduced annual rainfall and increased evaporation	Reduction in average rainfall levels of approximately 3% from current levels leads to changes in capacity to manage natural landscape.	Mainly along the GreenWay	Low	Assess exposure to increased soil erosion as a result of reduced net water balance. Consider soil profile more carefully.	1) Review overall landscape management framework to retain as much native flora/fauna as possible. 2) Refer to Section 17.4.
Increased wind speeds	Increased risk of debris and items, such as tree parts, being blown across the line, thereby increasing risk of derailment. (Note particular uncertainty of wind modelling, therefore % change in wind speed must be regarded with extra caution compared to data for other environmental variables.)	All locations	Low	Consider works program with local council bodies to manage tree density in areas close to tracks.	Tree maintenance to include regular checks to ensure trees not growing wildly and keep adequate distance to tracks.
Lightning, extreme temperatures and wind gusts	More frequent interruptions to mains power supply and more frequent and prolonged blackouts caused by air-conditioning demands, reduced generation and transformer efficiency.	All locations	Low	Investigate back-up power supply.	1) Ensure regular system notifications to public include updates on schedule breakdowns due to such interactions between energy generation and temperature. 2) Review arrangements on energy contractual terms to assess levels of energy security.
More frequent and severe heat waves	Impacts on passenger comfort as a result of more frequent runs of hot days above 35°C (4.4 compared to 3.6 currently). This can result in: ▪ air-conditioning units on trains failing ▪ ill passengers.	All locations	High	Determine the ambient temperature in light rail vehicles and stops during a prolonged heatwave, with severity projected at several time intervals out to 2100. Compute extra capacity of air-conditioning required to maintain acceptable temperature. Note that at about 40°C air-conditioning systems begin to lose efficiencies and at about 46°C they begin to lose operational capacity. Systems generally shut down at 55°C.	1) Cost and assess options to: provide required capacity at outset; or how to incorporate design features to facilitate increasing capacity as and when required. 2) Review guidelines for passenger comfort to determine if additional cooling hardware is required to take account of climate change.

IDENTIFICATION			ASSESSMENT	ANALYSIS — SUGGESTED DESIGN RESPONSE	ADAPTATION MEASURE
Climatic variable(s)	**Risk name**	**Locations**	**Initial risk priority**	**Risk treatment analysis**	**Possible treatment**
More frequent and severe heat waves	Increased operating and maintenance costs of air-conditioning systems of light rail vehicles from more frequent runs of hot days above 35°C (4.4 compared to 3.6 currently).	N/A	Medium	Model a range of plausible electricity cost increases out to 2100 to ensure they would not make the Light Rail's operation financially unviable.	Ensure air-conditioning systems are as energy efficient as possible to reduce exposure to cost increases and reduce GHG emissions
More frequent and severe heat waves	Increased extreme temperatures from more frequent runs of hot days above 35°C (4.4 compared to 3.6 currently) result in overhead wire sag and greater electrical resistance in conductors, leading to damage to OHW, service disruptions and greater losses and maintenance for conductors and transformers, with consequent increases in costs.	All locations	Low	Investigate and identify innovative design options to reduce temperatures in signalling field cabinets, as well as review vulnerable sections of track, with particular attention to low wire area.	Ensure design incorporates effects of extreme temperatures through innovative design measures, such as regulated tension wiring
More frequent and severe heat waves	Increased risk of rail line buckling from sudden temperature rises as a result of more frequent runs of hot days above 35°C (4.4 compared to 3.6 currently) rather than average gradual temperature increases.	All sections of track	High	Investigate and identify particularly vulnerable sections of track	Maintain track stability through regular maintenance, use concrete sleepers in place of wooden ones and use preventative measures, such as speed restrictions in extreme temperatures.
N/A	Increased operating costs due to higher carbon pricing.	N/A	High	Model a range of plausible electricity cost increases out to 2100 to ensure they would not make the Light Rail's operation financially unviable.	1) Consider further assessment of Marginal Abatement Cost Curves to assess commercial opportunities of reducing reliance on single energy source. 2) Consider implementing green energy practices, including trading in Renewable Energy Certificates market.

IDENTIFICATION			ASSESSMENT	ANALYSIS — SUGGESTED DESIGN RESPONSE	ADAPTATION MEASURE
Climatic variable(s)	**Risk name**	**Locations**	**Initial risk priority**	**Risk treatment analysis**	**Possible treatment**
Increased wind speeds	Higher likelihood of flying debris resulting in impacts and damage to vehicles and nearby equipment (Note particular uncertainty of wind modelling, therefore % change in wind speed must be regarded with extra caution compared to data for other environmental variables.)	All locations	Medium	Investigate and identify particularly vulnerable sections of track and areas with trees or loose structures close to the track.	Manage trackside trees, ensure trackside equipment is adequately mounted, clear line-side and design wind fences.
Increased annual average temperatures and increases in extreme temperatures	Impacts on the amount of movement required at bearings and expansion joints.	All locations	Low	Investigate stresses induced by higher temperatures in design and assessment of bearings and expansion joints to properly allow for adequate range of movement.	Review materials, technology and system design standards to ensure materials able to cope with increased temperatures are selected.
Increased frequency of lightning	Damage to underground cable networks, which take longer to repair than transformer damage.	All locations	Low	To be considered in the project's design.	To be considered in the project's design.

16.6 Summary of key climate change risks to the project

As the climate becomes more extreme and frequent in its severity, there are clearly going to be implications for the project's construction and operation phases. While rail infrastructure is considered relatively well protected against the effect of climate change compared to other transport infrastructure, there are some key areas that pose high vulnerability:

Earthworks/embankments/tunnelling: The seasonal shrinkage of soils will be increased by the hotter, drier weather, which is reflected in predictions of increased average temperatures (mean 2030 increase of 0.9°C from current levels), extreme temperatures (mean 2030 increase to 4.4 from 3.6 currently of number of runs of days above 35°C from current levels); this will lead to deeper cracks in cohesive soils, although structure foundations, such as piles or rafts, might be able to mitigate that risk. Consequently, it would be prudent to address methods of reducing the likelihood and intensity of problems associated with subsidence.

It is an accepted fact that the incidence of earthwork failure increases after an extended run of wet weather because the build-up of pore water pressures following wet weather increases the disturbing force on the soil and also reduces its shear strength. Extreme wet weather events are expected to be increasingly evident, as shown by the mean 2030 4% increase in change of 5 year–2 hour storm rainfall intensities. The generation of deeper cracks would allow water to penetrate further into a slope, and so earthwork failures might be started by heavy rainfall following an extended hot dry spell.

Drainage: Current designs of drains are based on historical data. It is unusual for designs to be based on anticipated weather conditions. However, it is important to consider how drainage could be affected by the potential increases in annual rainfall combined with other factors, such as higher ground water levels, and increased wind events. It would be prudent to further assess groundwater and hydrology characteristics.

Track, point and line-side equipment: Various lengths of track would be differently affected by climate change impacts. Problems of poor traction would occur where there is flooding, especially in parts where conductor rails are present. As projections show that the study area is expected to become warmer, with more hot days as evidenced by increase in number of hot spells (increasing to 4.4 in 2030 compared to current levels of 3.6), warmer summers may contribute to greater likelihood of rail buckling.

Lightning would have a particular impact on points; they would need to be protected through design measures, such as incorporating lightning conductors at strategic points alongside the track

Overhead Lines: Increased summer temperatures would increase the sag of overhead power cables; possible mitigation measures include using regulated tension wiring to counter thermal expansion. This may reduce the clearance between various structures, such as between cables and structures like trees and passing vehicular traffic. Consequently, these risks would have to be carefully evaluated. An increase in temperature might also reduce the capacity of overhead power lines by inducing greater electrical resistance to conductors.

Increased severity and frequency of extreme winds may raise the likelihood of damage to overhead wiring thereby resulting in increased to associated infrastructure damage. Wind-blown debris could also damage overhead lines and further research is needed to assess the effects of climate change-related extreme events on overhead line structures. The uncertainties of wind modelling need to be weighed heavily in considering mitigation actions and capital decisions for this variable.

Firstly, much of the statistical modelling has some limitations. It depends on the quality of the recorded data used and, for example, there have been limitations in measuring gust speeds because instruments have been calibrated for mean wind speeds. This is a severe shortcoming given that short gusts (1 to 3 seconds) are often the cause of much damage. Secondly, the calculation of confidence intervals for the wind hazard return period also increases in proportion to the return-period (years) considered. For observing stations with record lengths of 20 to 30 years, it has been found the derived return periods beyond about 500 years are too unreliable to use in practical applications. (Sanabria, LA & Cechet, RP 2007) For such reasons, it is important to consider more seriously the value-for-money equation in assessing the need for augmenting infrastructure on the basis of exposure to wind hazards.