Transport for NSW

Appendix I
Climate change assessment – additional information

NSW GOVERNMENT

This appendix provides additional information to support Chapter 21 (Climate change) including climate data; future climate scenarios; climate change risk assessment; and adaptation measures proposed for the project.

I-1 Background climate data

Baseline climate data was sourced from the Bureau of Meteorology (BoM) Parramatta North (Masons Drive) automatic weather station (site number 066124) for the 1990-2009 period and is summarised in Table I.1. Datasets for West Ryde, Meadowbank and Rhodes were used as the closest available datasets for the suburbs of Ermington, Melrose Park and Wentworth Point along the project site.

Further information regarding the climate variables that were identified as relevant to the project (see section 21.2.2) is provided in *Transport for NSW Climate Risk Assessment Guidelines* (Transport for NSW, 2021).

Table I.1 Background climate data

Climate variable		Camellia	Rydalmere	West Ryde	Meadowbank	Rhodes	Sydney Olympic Park
Heat vulnerability index	Heat vulnerability index (current state)	3	3	4	3	2	2
Disaster resilience index	Disaster resilience index (current state)	0.5	0.7	0.8	0.8	0.8	0.7
Temperature	Maximum temperature (including urban heat island)	49.1°C	48°C	49.5°C	47.5°C	48.6°C	50.5°C
	Minimum temperature	9.4°C	8.3°C	9.8°C	7.9°C	8.9°C	10.8°C
	Number of days over 35°C	78 days	64 days	84 days	60 days	71 days	99 days
	Number of days over 40°C	29 days	22 days	34 days	20 days	25 days	39 days
Average humidity	Average humidity at 40°C	54 per cent	53 per cent	53 per cent	53 per cent	54 per cent	54 per cent
Rainfall	Duration of heavy-rain periods, days (heavy rain period refers to consecutive days when rainfall exceeded 30 mm/day)	2 days	2 days	2 days	2 days	2 days	2 days

Climate variable		Camellia	Rydalmere	West Ryde	Meadowbank	Rhodes	Sydney Olympic Park
	Number of heavy rain periods (heavy rain period refers to consecutive days when rainfall exceeded 30 mm/day)	2	2	2	2	2	2
	Total amount of rain during a maximum rainfall period (mm) (rainfall over consecutive days)	160 mm	160 mm	160 mm	160 mm	160 mm	160 mm
	Daily precipitation rate (mm/hr)	38 mm/hr	38 mm/hr	38 mm/hr	38 mm/hr	38 mm/hr	38 mm/hr
	Daily precipitation, mm/day	124 mm/day	124 mm/day	124 mm/day	124 mm/day	124 mm/day	124 mm/day
	Number of days with rainfall intensity over 25 mm/h	1 day	1 day	1 day	1 day	1 day	1 day
	Drought duration, days (drought is defined as a period of more than 14 consecutive days with rainfall below 1 mm/day)	58 days	58 days	58 days	58 days	58 days	58 days
	Number of drought periods (no rain for over 2 weeks)	7	7	7	7	7	7
Soil moisture	Number of days with soil moisture below 20 per cent	5 days	5 days	5 days	5 days	5 days	5 days
Wind	Maximum wind speed (wind gust), km/h	67 km/h	67 km/h	67 km/h	67 km/h	67 km/h	67 km/h
	Number of days with wind speed over 65 km/h	1 day	1 days	1 day	1 day	1 day	1 day
Bushfire risk	Highest fire index	Not bushfire zone	Not bushfire zone	64	64	Not bushfire zone	Not bushfire zone
	Number of days with fire index over 25	Not bushfire zone	Not bushfire zone	11	11	Not bushfire zone	Not bushfire zone

Climate variable		Camellia	Rydalmere	West Ryde	Meadowbank	Rhodes	Sydney Olympic Park
Sea level rise	Sea level rise (maximum projection range), m – 2051-2090	2.44	2.44	2.44	2.44	2.44	2.44

I-2 Climate projection data

Qualitative future projection data for the study area was obtained from CSIRO's *Climate Change in Australia Projection Tools* (CSIRO and BOM, 2015) for the East Coast Data and supplemented by AdaptNSW (OEH) climate snapshots. This qualitative data indicated:

- average temperatures would continue to increase in all seasons
- more hot days and warm spells are projected to increase. Fewer frosts are projected.
- natural climate flexibility would remain the major driver of rainfall changes in the next few decades
- less rainfall in winter in the south but otherwise rainfall changes are unclear
- the intensity of heavy rainfall events would increase
- climate change would result in a harsher fire-weather climate in the future
- little change in mean surface wind speed is projected.

Climate projection data was taken from Transport for NSW climate risk tools 1 and 2 which use NSW and Australian Regional Climate Modelling (NARCLiM) 1.5 data released in 2021.

The NARCliM projection data within Transport for NSW's climate risk tools use the Representative Concentration Pathways (RCP) 8.5 emissions scenario, which represents a 'business as usual' high-emission scenario that assumes high population growth and slow technological progress, resulting in little curbing and continuing rapid rise of emissions throughout the 21st century.

Transport for NSW's climate risk tools were pre-populated with the quantitative projections listed in Table I.2.

Table I.2 Quantitative projections used in risk assessment

Projection	Emissions scenario	Timeframe	Source
RCP8.5	High emissions trajectory	2021-2050	Intergovernmental Panel on Climate Change (IPCC) (2015), NARCliM 1.5 (2021)
RCP8.5	High emissions trajectory	2051-2081	IPCC (2015), NARCliM 1.5 (2021)
RCP8.5	High emissions trajectory	2071-2100	IPCC (2015), NARCliM 1.5 (2021)

The selection of the three projection scenarios allows the assessment to consider both a short, medium and long-term scenario and to allow an appropriate assessment of all asset components.

Table I.3 shows the climate projection data for key climate variables for each of the areas of the project generated by Transport for NSW's climate risk tool 1, i.e. per above using the high emissions trajectory scenario (RCP 8.5) and including projected Urban Heat Island (UHI) effect for each area of the project.

Table I.3 Climate change projections for key climate variables (Camellia, Rydalmere and West Ryde)

Location	Camellia				Rydalmere				West Ryde			
Climate variable[1]	**Baseline 1990-2009)**	**2021-2050**	**2051-2080**	**2071-2100**	**Baseline (1990-2009)**	**2021-2050**	**2051-2080**	**2071-2100**	**Baseline (1990-2009)**	**2021-2050**	**2051-2080**	**2071-2100**
Heat vulnerability index (current state)	3	3	3	3	3	3	3	3	4	4	4	4
Disaster resilience index (current state)	0.5	0.5	0.5	0.5	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8
Maximum temperature (including UHI) (degrees Celsius (°C))	49.1°C	3.8°C	4.9°C	6.3°C	48°C	3.8°C	4.9°C	6.3°C	49.5°C	3.8°C	4.9°C	6.3°C
Minimum temperature	9.4°C	2.6°C	3.5°C	4.3°C	8.3°C	2.6°C	3.5°C	4.3°C	9.8°C	2.6°C	3.5°C	4.3°C
Number of days over 35°C	78 days	48	75	103	64 days	41	67	94	84 days	52	78	108
Number of days over 40°C	29 days	14	37	49	22 days	13	30	41	34 days	15	37	51
Average humidity at 40°C	0.54	1	-1	2	0.53	2	-2	2	53%	3	1	3
Duration of heavy-rain periods, days	2 days	0	0	1	2 days	0	1	1	2 days	0	0	1
Number of heavy rain periods	2	0	-1	0	2	0	-2	0	-1 from 2	0	-2	0
Total amount of rain during a maximum rainfall period, mm	160 mm	52	10	25	160 mm	52	10	25	160 mm	52	10	25
Precipitation rate, mm/h	38 mm/h	-1	1	12	38 mm/h	-1	1	12	38 mm/h	-1	1	12
Daily precipitation, mm/day	124 mm/d	-20	13	18	124 mm/d	-20	13	18	124 mm/d	-20	13	18
Number of days with rainfall intensity over 25 mm/h	1 day	0	1	1	1 day	0	1	1	1 day	0	1	1
Drought duration, days	58 days	0	5	3	58 days	0	5	3	58 days	0	5	3
Number of drought periods (no rain for over 2 weeks)	7	1	1	0	7	1	1	0	+1 from 7	1	1	0

Location	Camellia				Rydalmere				West Ryde			
Climate variable[1]	**Baseline 1990-2009)**	**2021-2050**	**2051-2080**	**2071-2100**	**Baseline (1990-2009)**	**2021-2050**	**2051-2080**	**2071-2100**	**Baseline (1990-2009)**	**2021-2050**	**2051-2080**	**2071-2100**
Number of days with soil moisture below 20%	5 days	-5	-5	-5	5 days	-5	-5	-5	5 days	-5	-5	-5
Wind speed, km/h	67 km/h	-1	-2	-1	67 km/h	-1	-2	-1	67 km/h	-1	-2	-1
Number of days with wind speed over 65 km/h	1 day	1	-1	0	1 day	1	-1	0	1 day	1	-1	0
Highest fire index	Not bushfire zone				Not bushfire zone				64	2	5	7
Number of days with fire index over 25	Not bushfire zone				Not bushfire zone				11	1	10	7
Sea level rise (maximum projection range), m – 2051-2090	+0.25 m	0.25	1.42	2.44	+0.25 m	0.25	1.42	2.44	+0.25 m	0.25	1.42	2.44

Note: 1. Shows the change from the baseline data for each projected period, with a negative number showing a decrease. The exception is data for the Heat vulnerability index, Disaster resilience index and Highest fire index, with the data showing the index value for each projected period.

Table I.4 Climate change projections for key climate variables (Meadowbank, Rhodes and Sydney Olympic Parks)

Location	Meadowbank				Rhodes				Sydney Olympic Park			
Climate variable[1]	Baseline (1990-2009)	2021-2050	2051-2080	2071-2100	Baseline (1990-2009)	2021-2050	2051-2080	2071-2100	Baseline (1990-2009)	2021-2050	2051-2080	2071-2100
Heat vulnerability index (current state)	3	3	3	3	2	2	2	2	2	2	2	2
Disaster resilience index (current state)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7
Maximum temperature (including UHI) (degrees Celsius (°C))	47.5°C	3.8°C	4.9°C	6.3°C	48.6°C	3.8°C	4.9°C	6.3°C	50.5°C	3.8°C	4.9°C	6.3°C
Minimum temperature	7.9°C	2.6°C	3.5°C	4.3°C	8.9°C	2.6°C	3.5°C	4.3°C	10.8°C	2.6°C	3.5°C	4.3°C
Number of days over 35°C	60 days	39	60	88	71 days	45	72	99	99 days	56	88	114
Number of days over 40°C	20 days	13	27	37	25 days	14	36	46	39 days	25	43	63
Average humidity at 40°C	0.53	-1	-1	1	0.54	1	-1	1	0.54	3	1	4
Duration of heavy-rain periods, days	2 days	0	0	1	2 days	0	0	1	2 days	0	0	1
Number of heavy rain periods	2	0	-1	0	2	0	-1	0	2	0	-1	0
Total amount of rain during a maximum rainfall period, mm	160 mm	52	10	25	160 mm	52	10	25	160 mm	52	10	25
Precipitation rate, mm/h	38 mm/h	-1	1	12	38 mm/h	-1	1	12	38 mm/h	-1	1	12
Daily precipitation, mm/day	124 mm/d	-20	13	18	124 mm/d	-20	13	18	124 mm/d	-20	13	18
Number of days with rainfall intensity over 25 mm/h	1 day	0	1	1	1 day	0	1	1	1 days	0	1	1
Drought duration, days	58 days	0	5	3	58 days	0	5	3	58 days	0	5	3
Number of drought periods (no rain for over 2 weeks)	7	1	1	0	7	1	1	0	7	1	1	0

Location	Meadowbank				Rhodes				Sydney Olympic Park			
Climate variable[1]	Baseline (1990-2009)	2021-2050	2051-2080	2071-2100	Baseline (1990-2009)	2021-2050	2051-2080	2071-2100	Baseline (1990-2009)	2021-2050	2051-2080	2071-2100
Number of days with soil moisture below 20%	5 days	-5	-5	-5	5 days	-5	-5	-5	5 days	-5	-5	-5
Wind speed, km/h	67 km/h	-1	-2	-1	67 km/h	-1	-2	-1	67 km/h	-1	-2	-1
Number of days with wind speed over 65 km/h	1 day	1	-1	0	1 day	1	-1	0	1 day	1	-1	0
Highest fire index	64	2	5	7	Not bushfire zone				Not bushfire zone			
Number of days with fire index over 25	11	1	10	7	Not bushfire zone				Not bushfire zone			
Sea level rise (maximum projection range), m – 2051-2090	+0.25 m	0.25	1.42	2.44	+0.25 m	0.25	1.42	2.44	+0.25 m	0.25	1.42	2.44

Note: 1. Shows the change from the baseline data for each projected period, with a negative number showing a decrease. The exception is data for the Heat vulnerability index, Disaster resilience index and Highest fire index, with the data showing the index value for each projected period.

I-3 Climate change risk assessment

The climate change risk assessment identified risks and risk mitigation measures associated with the predicted impacts of climate change on the design, construction, and operation of the project. The objectives of this assessment are to:

- identify significant potential impacts of climate change on the proposal's infrastructure and service delivery
- assess the level of associated risks.

This assessment considered the impact of climate change on the project rather than the impact of the project on future climate change. The approach to the climate change risk assessment and adaptation planning process was consistent with the approach outlined in the *Transport for NSW Climate Risk Assessment Guidelines version 4.1* (Transport for NSW, 2021a) and conforms to the following standards:

- AS/NZS ISO 31000:2009 Risk management – Principles and guidelines (Standards Australia, 2009a)
- AS 5334–2013 Climate change adaptation for settlements and infrastructure – a risk based approach (Standards Australia, 2013).

The analysis involved assessing the risk level of each identified potential impact by identifying the consequences of the impact and the likelihood that the impact can occur using Transport for NSW's risk criteria (Transport for NSW, 2020d), which are outlined in Appendix G (Preliminary hazard analysis).

Table I.5 shows the results of the risk assessment for the inherent risks for the three climate change projections for the project.

Table I.5 Inherent climate change risks and ratings

Risk ID	Climate hazard	Risk description	Direct/ indirect impact	Risk rating		
				2021-2050	2051-2080	2071-2100
CR1	Heat-related	Bushfires in the region cause direct damage to vegetation and project landscaping efforts.	Direct	Low	Low	Low
CR2	Heat-related	Bushfire smoke impacts infrastructure (especially substations) resulting in malfunctions.	Direct	Low	Low	Low
CR3	Heat-related	Bushfire smoke blown onto the construction site impacts the health of workers.	Direct	High	-	-
CR10	Heat-related	Bushfire smoke in the area during project operation results in delay in light rail service and customer complaints.	Direct	Medium	Medium	Medium
CR11	Heat-related	Bushfire smoke impacts operations staff resulting in illness.	Direct	High	High	High
CR12	Heat-related	Dust storm/bushfire particles affecting light rail vehicles (esp. blocking filters) operations.	Direct	Medium	Medium	Medium
CR13	Precipitation-related	Risk of insufficient council drainage system impacting on project infrastructure and assets during intense rainfall events.	Direct	Medium	Medium	Medium

Risk ID	Climate hazard	Risk description	Direct/ indirect impact	Risk rating		
				2021-2050	2051-2080	2071-2100
CR14	Precipitation-related	High intensity rainfall creates a flood that damages project infrastructure, resulting in damage and cost to repair/ replace.	Direct	Medium	Medium	High
CR15	Precipitation-related	Potential to cause flooding up and downstream - impacting on nearby infrastructure and residences.	Indirect	Medium	Medium	High
CR16	Precipitation-related	High intensity rainfall creates a flood that damages project infrastructure, resulting in delay in light rail service and customer complaints.	Direct	High	High	High
CR17	Precipitation-related	High intensity rainfall and increased water velocity in river causes scour issues on bridges and reduced design life (increased cost to repair/ replace).	Direct	Medium	Medium	Medium
CR18	Precipitation-related	Regime impacts threatened flora species (eg. *Wilsonia backhousiia*) and fauna species (eg. Green and Golden Bell Frog (*Litoria aurea*)).	Direct	Very High	Very High	Very High
CR19	Precipitation-related	High intensity rainfall (and hail) impacts construction and results in multiday downtime (1-7 days) which results in loss of costs.	Direct	Medium	-	-
CR20	Precipitation-related	High intensity rainfall creates a flood or surface flows of water that exceed the capacity of drainage and stormwater infrastructure, resulting in damage and cost to repair/ replace.	Direct	High	High	High
CR21	Precipitation-related	High intensity rainfall (and hail) results in delay in light rail service and customer complaints.	Direct	Medium	Medium	Medium
CR22	Precipitation-related	Loss of vegetation/ landscaping areas (especially in sloped areas) prior to plants developing established root system.	Indirect	Low	Low	Low
CR69	Precipitation-related	High intensity rainfall causes wet patches around foundations causing tracks to shift and significant cost to repair/replace.	Direct	Low	Low	Low
CR70	Precipitation-related	High intensity rainfall causes scour and erosion impacts on surrounding waterways and associated environmental impacts (e.g. water quality, ecological implications for species).	Direct	Medium	Medium	Medium
CR71	Precipitation-related	High intensity rainfall causes wet patches around the track where customers stand which can cause slips and trips causing injury to customers.	Direct	Medium	Medium	Medium

Risk ID	Climate hazard	Risk description	Direct/ indirect impact	Risk rating		
				2021-2050	2051-2080	2071-2100
CR79	Precipitation-related	Potential damage of the light rail vehicles from hail due to not being housed under cover causing damage to assets.	Direct	Medium	Medium	Medium
CR80	Precipitation-related	Hail impact on customers waiting for light rail services causing injuries.	Direct	Medium	Medium	Medium
CR81	Precipitation-related	Hail damage to general infrastructure (stops, substations, vegetation, trees), increasing repair costs.	Direct	Medium	Medium	Medium
CR82	Precipitation-related	During extreme hail storms, risk of traction issues up some steep grades may cause operational delays.	Direct	Medium	Medium	Medium
CR84	Precipitation-related	Soil and groundwater in Camellia, Wentworth Point and Sydney Olympic Park is potentially contaminated from historical activities. Ground disturbance activities have the potential to cause water quality impacts due to run off from contaminated land.	Direct	Medium	Medium	Medium
CR85	Precipitation-related	Increase in rainfall intensity leading to flooding and disruption of critical systems.	Direct	Medium	Medium	Medium
CR23	Drought-related	Drought and low soil moisture causes vegetation stress, failure of project landscaping and increased cost to irrigate/replace.	Indirect	Medium	Medium	Medium
CR24	Drought-related	Drying out of foundations, cracking of underlying materials causing increased maintenance or replacement.	Direct	Medium	Medium	Medium
CR25	Drought-related	Drought and low soil moisture causes erosion of batters, scouring in waterways (e.g. culverts slippage of tracks) and cost to repair/replace.	Direct	High	High	High
CR26	Drought-related	Water restrictions applied during the construction period limit the availability of water for construction purposes and cause a delay in project schedule.	Direct	Medium	-	-
CR27	Drought-related	Drought and low soil moisture causes slope instability due to loss of trees and vegetation, increasing erosion and costs to repair.	Direct	Medium	Medium	Medium
CR29	Drought-related	Drought and low soil moisture causes vegetation stress and branches/ debris falling on the tracks, resulting in delays to services and customer complaints.	Direct	Medium	Medium	Medium
CR30	Drought-related	Water restrictions result in reduced vehicle washes and customer complaints.	Direct	Low	Low	Low

Risk ID	Climate hazard	Risk description	Direct/ indirect impact	Risk rating		
				2021-2050	2051-2080	2071-2100
CR88	Drought-related	Decrease in mean rainfall, leading to increase in potable water demand, resulting in higher water costs.	Direct	Medium	Medium	Medium
CR28	Other	Constructed bridges create shading that changes the composition of vegetation (mangroves and salt marshes) at the location, potentially impacting on threatened flora and flora communities.	Indirect	High	High	High
CR31	Other	Extreme wind during construction period blows falling trees and debris onto construction site, blocking access roads, stopping work and causing a delay in project schedule.	Direct	Medium	Medium	Medium
CR32	Other	Extreme wind causes trees to fall on top of overhead wiring, causing damage to wiring and delays in operation and safety concerns.	Direct	Medium	Medium	Medium
CR33	Other	Extreme wind in operation period causes damage to electric lines and other infrastructure, resulting in an increase in maintenance and operational costs to repair and replace damaged infrastructure.	Direct	Medium	Medium	Medium
CR34	Other	Extreme wind in operation period causes damage to electric lines and other infrastructure (e.g. poles, electric wires and above ground distribution boards), resulting in delays to service and customer complaints.	Direct	Medium	Medium	Medium
CR35	Other	Extreme wind in operation period causes damage to electricity lines and other infrastructure (e.g. poles, electric wires and above ground distribution boards), resulting in a significant safety incident (e.g. electrocution).	Direct	High	High	High
CR36	Other	Extreme wind during operations period damage transmission lines and causes power outages of services (including signalling), resulting in service delays and customer complaints.	Direct	Medium	Medium	Medium
CR37	Other	Extreme wind event coinciding with a heat wave during operations period damages transmission lines and causes power outages of services (including signalling), resulting in significant safety incident (e.g. customers stranded on rail in high temperatures).	Direct	High	High	High
CR38	Other	Extreme wind during operations period blows falling trees and debris onto site causing a delay to services and customer complaints.	Direct	Medium	Medium	Medium

Risk ID	Climate hazard	Risk description	Direct/ indirect impact	Risk rating		
				2021-2050	2051-2080	2071-2100
CR39	Other	Extreme wind event causes shutdown of the light rail service due to safety reasons, resulting in stranded customers and customer complaints.	Direct	Medium	Medium	Medium
CR40	Other	Lightning strike causes direct damage to track assets (e.g. concrete sleepers, steel rail, signalling equipment), resulting in significant costs to repair/replace.	Direct	Medium	Medium	Medium
CR42	Other	Dead or dry vegetation becomes a fire hazard and ignites from lightning strike or other source, resulting in significant safety incident.	Direct	Medium	Medium	Medium
CR43	Other	Dead or dry vegetation becomes a fire hazard and ignites from lightning strike or other source, resulting in significant infrastructure damage and cost to repair/ replace.	Direct	Medium	Medium	Medium
CR44	Other	Lightning in the region during operations damage transmission lines and cause power outages of services (including signalling), resulting in significant safety incident (e.g. customers stranded on rail in high temperatures) and delays to service.	Direct	Medium	Medium	Medium
CR72	Other	The risk of increased flow under bridge caused by sea level rise causing shutdown of services.	Direct	Medium	Medium	Medium
CR73	Other	Ingress of salt water into the embankment and lower pavement layers result in reduced performance life and cost to repair/manage.	Direct	Medium	Medium	Medium
CR74	Other	Impacts from sea level rise cause track movement and significant cost to repair/replace.	Direct	Medium	High	Very High
CR75	Other	Impacts from sea level rise causes track movement and delays to light rail services, resulting in customer complaints	Direct	Medium	Medium	High
CR76	Other	Sea level rise and flooding changes hydrological regime that mangrove and salt marsh conditions rely on, changing the extent and composition of flora and fauna communities (including threatened species).	Direct	Medium	Medium	High
CR77	Other	Impact to pedestrian access to light rail and active transport services/ infrastructure due to king tides and flooding causing customer complaints.	Direct	Medium	Medium	High
CR83	Other	Construction activities impact mangroves and salt marshes, changing the extent and composition of flora and fauna communities (including threatened species).	Direct	High	-	-

Risk ID	Climate hazard	Risk description	Direct/ indirect impact	Risk rating		
				2021-2050	2051-2080	2071-2100
CR4	Heat-related	Bushfire smoke blown onto the construction site impacts construction and results in stop work and delay in project schedule.	Direct	Medium	-	-
CR5	Heat-related	Bushfires in the region during construction period cause road closures and increased traffic, resulting to delays in project schedule.	Direct	Medium	-	-
CR6	Heat-related	Bushfires impact on regional electricity supply, requiring operators to reduce/ stop operations to conserve electricity supply.	Direct	Medium	Medium	Medium
CR7	Heat-related	Bushfires in the region during operations damage transmission lines and cause power outages of services (including signalling), resulting in service delays and customer complaints.	Direct	Medium	Medium	Medium
CR8	Heat-related	Bushfires in the region during operations damage transmission lines and cause power outages of services (including signalling), resulting in significant safety incident (e.g. customers stranded on rail in high temperatures).	Direct	Medium	Medium	Medium
CR9	Heat-related	Bushfire smoke in the area during project operation impacts the health of customers.	Direct	High	High	High
CR45	Heat-related	High daily temperatures and solar radiation cause road asphalt to melt, resulting in project schedule delay and increased costs.	Direct	Medium	Medium	Medium
CR46	Heat-related	High daily temperatures and solar radiation cause road asphalt to melt, resulting in delayed services and customer complaints.	Direct	Medium	Medium	Medium
CR47	Heat-related	High daily temperatures during construction period shortens the concrete curing duration period, causing concrete shrinking and cracking.	Direct	Medium	-	-
CR48	Heat-related	Higher temperatures throughout the year require increased amount of energy usage for air conditioning and other cooling mechanisms and result in increase in project electricity and energy costs.	Direct	Low	Low	Low
CR49	Heat-related	Extreme heat days result in the footpath/ pavement heating to excessive temperatures that are not suitable for customers.	Direct	Medium	High	High

Risk ID	Climate hazard	Risk description	Direct/ indirect impact	Risk rating		
				2021-2050	2051-2080	2071-2100
CR50	Heat-related	Wentworth Point bridge structure is exposed to extreme heat and will become over heated for workers and customers.	Direct	High	High	High
CR51	Heat-related	Higher temperatures causing steel to expand more on the bridges such as the bridge at Wentworth point which will cause reduced design life and increased costs to repair/ replace.	Direct	Medium	Medium	Medium
CR52	Heat-related	Extreme temperatures and solar radiation degrade batteries, causing an explosion/fire risk and significant safety event.	Direct	High	High	High
CR53	Heat-related	Heat wave during construction period impacts the health of workers (heat stroke) and results in lost time injury.	Direct	Medium	-	-
CR54	Heat-related	Heat wave during construction period results in stop work and delay in project schedule (1-7 days).	Direct	High	-	-
CR55	Heat-related	Heat wave during construction period results in power outage that stops work and causes delays in project schedule.	Direct	Medium	-	-
CR56	Heat-related	Heat wave during operations period results in power outage that causes service delays that impact the health of workers and customers (public safety incidents).	Direct	High	High	High
CR57	Heat-related	Heat wave during operations causes sag of overhead contact wire and reduced clearance resulting in high vehicles striking the cables and causing serious injury from electrocution.	Direct	High	High	High
CR58	Heat-related	Higher temperatures throughout the year impacts traction equipment (substations), track and power equipment and causes faster degradation.	Direct	Medium	Medium	Medium
CR59	Heat-related	Extreme heat on regional electricity supply, requiring operators to reduce/stop operations to conserve electricity supply.	Direct	Low	Low	Low
CR60	Heat-related	Heat wave causes vegetation stress, failure of project landscaping and increased cost to replace.	Direct	Medium	Medium	Medium
CR61	Heat-related	Extreme temperatures and solar radiation cause degradation of timber finishes and increased cost to repair/replace.	Direct	Low	Low	Low
CR62	Heat-related	Extreme temperatures and solar radiation make surfaces hot to touch, resulting in safety incident with customers.	Direct	Medium	Medium	Medium

Risk ID	Climate hazard	Risk description	Direct/ indirect impact	Risk rating		
				2021-2050	2051-2080	2071-2100
CR63	Heat-related	Extreme temperatures and solar radiation degrade project materials, resulting in equipment malfunction (e.g. external lighting, passenger information displays, integrated service cabinets, batteries), delays to services surfaces and customer complaints.	Direct	Medium	Medium	Medium
CR64	Heat-related	Heat wave during operations period impacts the health of workers and customers (at stops and while on vehicles) resulting in lost time injuries and public safety incidents.	Direct	High	High	High
CR65	Heat-related	Heat wave during operations period damages the rails tracks and results in delayed services and customer complaints.	Direct	Medium	Medium	Medium
CR66	Heat-related	The elastomer used in the rail support will have a reduced design life due to extreme heat, causing increased costs to repair and downtime of rails services.	Direct	Low	Low	Low
CR67	Heat-related	Rail becoming overheated, rail can get to 70 - 80 degrees Celsius causing stress around the tight curves and radii with thermal expansion as the rail will expand more on the curves and radii and become damaged quicker.	Direct	Low	Medium	Medium
CR68	Heat-related	Heat wave during operations period damages the rails tracks and results in service delays that impact the health of workers and customers (public safety incidents).	Direct	Medium	Medium	Medium
CR78	Heat-related	Air-conditioning does not cope with high temperatures and windows are inoperable, leading to uncomfortable conditions on board for operators and customers.	Direct	Medium	Medium	Medium
CR86	Heat-related	Heat wave during operations impacting people's health at stops (e.g. fainting requiring medical attention).	Direct	High	High	High
CR87	Heat-related	Heat wave (lasting 7 days) affecting normal light rail operations resulting in delays.	Direct	Medium	Medium	Medium
CR89	Heat-related	Extreme temperatures and urban heat island effect impact on threatened fauna species in project area (eg. Grey Headed Flying Fox (*Litoria aurea*)).	Indirect	High	Very High	Very High

I-4 Climate change adaption measures

Based on the identified risks and potential impacts, appropriate adaptation measures and/or design strategies are recommended. Adaptation measures can be grouped according to the type of treatment. A number of guiding principles were considered when developing and selecting adaptation measure, including:

- Measures that deliver 'no regret' or 'limited regret' outcomes. No-regrets treatments are measures that would deliver net benefits and should be undertaken anyway, regardless of whether climate change is an issue. No-regrets treatment examples include treatment measures that are cost neutral (possibly involving an initial capital investment but reducing overall costs in the longer term) and improved management practices (e.g. strategic planning).
- Win-win measures that address the climate change risks while also offering other environmental, social or economic benefits. These measures may come from a climate change need that can be designed to offer additional benefit with little additional cost, or where measures are introduced for reasons other than climate change but could be moulded to deliver adaptation benefits.
- Flexible and adaptive measures that may be implemented incrementally, to minimise the chance of implementing ill-directed or over-compensatory measures in the face of climate uncertainty. This also includes making adaptation measures scalable, and specific in cases where multiple different adaptation measures may need to be adopted to reduce risks across different asset components. For example, flooding where a different adaptation measure might be adopted for electrical systems verses track infrastructure.

Transport for NSW's climate risk tool 2 requires identification of adaptation measures/ risk treatment for the following categories:

- **Hard adaptation** – relies predominantly on human-built infrastructure and may be complex and capital intensive. For example, pavement design includes treatments to mitigate the effect of varying soil moisture.
- **Green adaptation** – includes forms of natural infrastructure or natural capital, such as ecosystems and forests. For example, tree planting and wetlands can complement storm water infrastructure such as drains by reducing surface runoff and increasing infiltration into soils and groundwater.
- **Soft adaptation** – includes simple and modular technologies that do not require large outlays of capital or human resources and which have the ability to respond to alterations in climate change projections. For example, investigate subsoil drainage.

Table I.6 lists the adaptation measures identified for each climate change related risk with a high rating or higher. It also provides the residual risk rating for the three climate change projections, following application of the adaption measures. These would be reviewed, adapted and prioritised as appropriate as the design progresses considering the initial capital investment and longer term costs, level of climate change risk mitigation, and other residual risks associated with the measure.

Table I.6Climate change adaption measures and residual risk ratings

Risk ID	Risk description	Potential adaptation measures	Timing of adaptation measures	Residual risk rating		
				2021 – 2050	2051-2080	2081-2100
CR3	Bushfire smoke blown onto construction site impacts the health of workers.	Develop/revise construction work health and safety plan to include providing correct PPE (respirators) and protocols (rescheduling non-essential works) to account for smoke.	Construction Design / Operation	Low	n/a	n/a
CR9	Bushfire smoke in the area during operation impacts the health of customers.	Emergency response plan to consider impacts from bushfire smoke on commuters. Regularly maintain air conditioning filters on light rail vehicles through consideration in the maintenance schedule.	Design/ Operation	Low	Low	Low
CR11	Bushfire smoke impacts operations staff resulting in illness.	Identify as a risk to be managed in operations plan and/or emergency response plan. Consider provision of P2 masks for workforce and maintenance of air quality filters when smoke is present.	Operation	Low	Low	Low
CR49	Extreme heat days result in the footpath/ pavement heating to excessive temperatures that are not suitable for customers.	Consider solar reflectance index (SRI) in pavement selection adaptation. Consider permeable pavements. Design canopy cover over pavements where possible. Increase canopy of street tree shading to reduce heat island effect.	Design	Low	Low	Low
CR50	Melrose Park to Wentworth Point bridge structure is exposed to extreme heat and will become overheated for workers and customers.	Enable shaded rest stops along the bridge. Enable some shaded protection for the maintenance access routes. SRI of bridge materials to minimise heat radiation and increase reflectivity. Develop and maintain emergency response plan (includes treatment options for heat waves).	Design	Low	Low	Low
CR52	Extreme temperatures and solar radiation degrade batteries, causing an explosion/ fire risk and significant safety event.	Ensure batteries are in cool storage at depot site. Backup power/generator to support. Ensure batteries are kept at a certain temperature (within the vehicles as a form of insulation). Include battery fire events in emergency response plan. Develop a maintenance schedule of testing and maintenance of batteries (i.e. adaptative design for when batteries need to be replaced).	Operation	Low	Low	Low

Risk ID	Risk description	Potential adaptation measures	Timing of adaptation measures	Residual risk rating		
				2021 – 2050	2051-2080	2081-2100
CR54	Heat wave during construction results in stop work and delays to project schedule (1-7 days).	Safety health environment and quality (SHEQ) plan to consider respite areas. Provide recommendations for contractual mechanisms to manage extreme heat events.	Construction	Low	n/a	n/a
CR56	Heat wave during operation results in power outage that causes service delays that impact the health of workers and customers (public safety incidents)	Maximise use of batteries or hydrogen cells on light rail vehicles to minimise impact of power failures on light rail service (i.e. battery powered vehicle can drop passengers into area with overhead cables if required). Design cooler stops (e.g. trees, materials selection). Include heat wave contingency in operational plans (replacement buses and comfort of passengers at replacement bus stops). Consider customer comfort at temporary replacement bus stops.	Design/ Operation	Low	Low	Medium
CR57	Heat wave during operation causes sag of overhead contact wire and reduced clearance resulting in high vehicles striking the cables and causing serious injury from electrocution.	Conduct sag calculations to consider worst case temperature range. Review current standards around design of overhead wiring. Ensure temperature range is accommodated and maximum temperature range includes future projections (see British Standard *BS EN 50119:2000 – EN50119 Railway applications. Fixed installations. Electric traction overhead contact lines*).	Design	Low	Low	Medium
CR64	Heat wave during operation impacts the health of workers and customers (at stops and while on vehicles) resulting in lost time injuries and public safety incidents.	Install sustainable track form to help mitigate urban heat island effect. Design cooler stops to maximise stop canopy structure (e.g. shading) and consider material selection to reduce heat transfer on contact. Investigate further options to include water bubblers at or near stops. Include heat wave contingency in operational plans and emergency response plan.	Design	Low	Medium	Medium

Risk ID	Risk description	Potential adaptation measures	Timing of adaptation measures	Residual risk rating		
				2021 – 2050	2051-2080	2081-2100
CR86	Heat wave during operation impacting people's health at stops (e.g. fainting requiring medical attention).	Install sustainable track form to help mitigate urban heat island effect. Design stops to maximise their ability to provide cool refuge during heat events. Investigate options to manage surface treatments to minimise impacts of heat (e.g. use cooler (high albedo) materials.	Design	Low	Low	Medium
CR89	Extreme temperatures and urban heat island effect impact on threatened fauna species.	Install sustainable track form to help mitigate urban heat island effect. Urban landscaping to increase tree canopy to reduce impacts of urban heat island effect.	Design/ Operation	Medium	High	High
CR25	Drought and low soil moisture causes erosion of batters, scouring in waterways (e.g. culverts slippage of tracks) and cost to repair/replace.	Landscape design to consider and respond to erosion of batters and scouring in waterways.	Design	Low	Low	Low
CR14	High intensity rainfall creates a flood that damages project infrastructure, resulting in damage and cost to repair/ replace.	Drainage designed to accommodate increased rainfall intensity from climate change. Appropriate design standard would be developed or adopted for drainage infrastructure which consider climate change. Critical project infrastructure constructed in the stabling and maintenance facility located above the probable maximum flood, where required Design to retain and promote infiltration at a local scale, where suitable. Investigate integrating precinct design for Camellia and light rail corridor with flood planning to incorporate future ground and building RLs (including designing drainage to accommodate the effects of sea level rise). Project team to consult with City of Parramatta Council and communicate perceived risks to inundation of surrounding local drainage system.	Design	Medium	Medium	Medium

Risk ID	Risk description	Potential adaptation measures	Timing of adaptation measures	Residual risk rating		
				2021 – 2050	2051-2080	2081-2100
CR15	Potential to cause flooding up and downstream - impacting on nearby infrastructure and residences.	Drainage designed to accommodate increased rainfall intensity from climate change. Appropriate design standard would be developed or adopted for drainage infrastructure which consider climate change. Critical project infrastructure constructed in the stabling and maintenance facility located above the probable maximum flood, where required Consult with relevant council and communicate perceived risks to inundation of surrounding local drainage system.	Design/ Operation	Low	Medium	Medium
CR16	High intensity rainfall creates a flood that damages project infrastructure, resulting in delay in light rail service and customer complaints.	Appropriate design standard would be developed or adopted for drainage infrastructure which consider climate change. Critical project infrastructure constructed in the stabling and maintenance facility located above the probable maximum flood, where required Investigate how critical systems are elevated above probable maximum flood level to maintain signals. Critical to light rail systems designed to incorporate adequate resilience to accommodate climate change Design standards for remainder of asset. Consult with relevant council and communicate perceived risks to inundation of surrounding local drainage system. Project drainage design accommodates anticipated additional flows as a result of climate change (and increase rainfall intensity). Consultation with Council regarding stormwater adequacy.	Design/ Operation	Medium	Medium	Medium

Risk ID	Risk description	Potential adaptation measures	Timing of adaptation measures	Residual risk rating		
				2021 – 2050	2051-2080	2081-2100
CR20	High intensity rainfall creates a flood where surface flows of water exceed the capacity of drainage and stormwater infrastructure, resulting in damage and cost to repair/ replace.	Appropriate design standard would be developed or adopted for drainage infrastructure which consider climate change. Critical project infrastructure constructed in the stabling and maintenance facility located above the probable maximum flood, where required Consult with the relevant council and communicate perceived risks to inundation of surrounding local drainage system and stormwater adequacy.	Design	Medium	Medium	Medium
CR28	Constructed bridges create shading that changes the composition of vegetation (mangroves and salt marshes) at the location, potentially impacting threatened flora and flora communities.	Minimisation of shade impacts through the design development process and any residual impacted vegetation would be considered in project offsetting requirements.	Design	High	High	High
CR74	Impacts from sea level rise cause track movement and significant cost to repair/ replace	Undertake additional flood modelling and sensitivity testing to further understand and gain consensus on flooding impacts associated with climate change, including those from sea level rise and king tides. Develop further design parameters/objectives in design development, using sensitivity testing to design out all high and extreme inherent risks.	Design	Medium	Medium	Medium
CR75	Impacts from sea level rise causes track movement and delays to light rail services, resulting in customer complaints	Undertake additional flood modelling and sensitivity testing to further understand and gain consensus on flooding impacts associated with climate change, including those from sea level rise and king tides. Develop further design parameters/objectives in design development, using sensitivity testing to design out all high and extreme inherent risks.	Design	Medium	Medium	Medium

Risk ID	Risk description	Potential adaptation measures	Timing of adaptation measures	Residual risk rating		
				2021 – 2050	2051-2080	2081-2100
CR76	Sea level rise and flooding changes hydrological regime that mangrove and salt marsh conditions rely on, changing the extent and composition of flora and fauna communities (including threatened species).	Undertake additional flood modelling and sensitivity testing to further understand and gain consensus on flooding impacts associated with climate change, including those from sea level rise and king tides. Develop further design parameters/objectives in design development, using sensitivity testing to design out all high and extreme inherent risks. Residual impacted vegetation to be considered in project offsetting requirements.	Design	Medium	Medium	High
CR77	Impact to pedestrian access to Light Rail and active transport services/ infrastructure due to seal level rise (e.g., king tides) and flooding causing customer complaints	Undertake additional flood modelling and sensitivity testing to further understand and gain consensus on flooding impacts associated with climate change, including those from sea level rise and king tides. Develop further design parameters/objectives in design development, using sensitivity testing to design out all high and extreme inherent risks.	Design	Medium	Medium	Medium
CR83	Construction activities impact mangroves and salt marshes, changing the extent and composition of flora and fauna communities (including threatened species).	A flora and fauna management plan would be prepared and implemented during construction to minimise the potential for impacts during construction.	Design/ Construction	Medium	n/a	n/a
CR35	Extreme wind in operation period causes damage to electricity lines and other infrastructure (e.g. poles, electric wires and above ground distribution boards), resulting in a significant safety incident (e.g. electrocution).	System designed with n-1 contingency – i.e. if one substation fails the system will still have electricity supply. Design to *BS EN 50119:2000 – EN50119 Railway applications. Fixed installations. Electric traction overhead contact lines* for electrical isolation to prevent electrocution when e.g. lines are down. Light rail vehicles designed to maximum wind speeds, as per codes, with system shut down when wind speeds reach above 130 km/h. Wires are designed to withstand wind speeds up to 130 km/h.	Design	Low	Low	Low

Risk ID	Risk description	Potential adaptation measures	Timing of adaptation measures	Residual risk rating		
				2021 – 2050	2051-2080	2081-2100
CR37	Extreme wind event coinciding with a heat wave during operations period damages transmission lines and causes power outages of services (including signalling), resulting in significant safety incident (e.g. customers stranded on rail in high temperatures).	Wires are designed to withstand wind speeds up to 130 km/h. System designed with n-1 contingency – i.e. if one substation fails the system will still have electricity supply. Maximise use of batteries or hydrogen cells on light rail vehicles to enable vehicles to drop customers off and move to a safe space during extreme wind event/electrical failure. Develop and maintain emergency response plan (includes contingency for back-up bus service).	Design / Operation	Low	Low	Low