TfNSW Climate Risk Assessment Guidelines

DMS-SD-081/4.0

Supporting Document – Applicable to Infrastructure and Place

Divisional Management System

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Version	Key Author	Date of approval	Doc. control no.	Summary of change
1.0	Rebecca Miller	1 March 2016	DS#4910686_1	Document created to assess climate risk
2.0	Jonathan Zea	15 November 2016	DS#4910686_5	Rebranded to I&S
3.0	Rebecca Miller	19 February 2018	DS#4910686_7	Document is updated to better enable climate risk decision-making to inform the earlier stages of a project's delivery A pre-screening tool to support the consideration and assessment of climate risk from pre-feasibility stage is added
3.1	Jonathan Zea	20 March 2019	DS#4910686_9	Rebranded to Infrastructure and Place (IP).
3.2	Jonathan Zea	26 August 2019	DS#4910686	DMS update
4.0	Veronika Emetc	23 March 2021		The document is updated to include a new climate risk assessment methodology, add more recent data and publications and enable the inclusion of the climate change risk assessment into the Asset Management Framework
4.1	Chris Royal	26 August 2021		Minor amendments around workshop requirements.

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Glossary

AR4	The Intergovernmental Panel on Climate Change Fourth Assessment Report published in 2007
AR5	The Intergovernmental Panel on Climate Change Fifth Assessment Report published in 2014
CRA	Climate Risk Assessment
CO2-e	Carbon Dioxide Equivalent
ECV	Essential Climate Variable
EIS	Environmental Impact Statement
FBC	Final Business Case
FFDI	Forest Fire Danger Index
GCM	General Circulation Model
IP	Infrastructure and Place Division
IPCC	Intergovernmental Panel on Climate Change
ISCA	Infrastructure Sustainability Council of Australia
NARCliM	NSW / ACT Regional Climate Modelling project
OEH	NSW Office of Environment and Heritage
ISO	International Organization for Standardization
REF	Review of Environmental Factors
SBC	Strategic Business Case
SDG	Sustainable Development Guidelines
SFAIRP	so far as is reasonably practicable
TERM	Transport for NSW Enterprise Risk Management
TfNSW	Transport for NSW
TSR	Transport for NSW Standard Requirements
UNFCCC	The United Nations Framework Convention on Climate Change
Asset Management	is defined as “a strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on both engineering and economic analysis based on quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain the desired state of good repair over the life cycle of the assets at minimum practicable cost.’’[1]

Baseline	a reference period from which changes can be evaluated[2].
Climate Change	(a) IPCC defines climate change as: “a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or land use”[1]. (b) UNFCCC defines climate change as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods”.
Climate change impacts	is the change in conditions that results in severe weather events.
Climate change adaptation (mitigation of climate risks)	described as “an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities”[3]
Climate resilience	is the ability to anticipate, prepare for, respond to and adapt to incremental change and sudden disruptions associated with climate change
Climate risk (used interchangeably with Climate Change Risk)	is a potential impact (event-driven shocks and long-term stresses) of existing natural hazards and climate change-driven natural hazards on the assets Climate risk is a function of probability and consequence; it relates to an asset's failure and the consequence associated with that failure.
Climate system	Earth's climate arises from the interaction of five major climate system components: the atmosphere, the hydrosphere, the cryosphere, the lithosphere, and the biosphere.
Consequence	defined as the extent to which the system, environment, economy, and society might be adversely affected under a given scenario.[4] It may include tangible: damage or disruption to assets, delays, liability due to failure to foresee and mitigate losses from any physical risks, or intangible consequences: health impacts to the community and/or staff. According to TERM, a consequence is the impact of an event on an objective. To assess the possible consequences of an event you need to work from the point of view that the risk has already occurred.
Disaster resilience	is the capacity to prepare for, absorb and recover from natural hazards, and to learn, adapt and transform in ways that enhance these capacities in the face of future events[5]. Disaster resilience arises from many social, economic and institutional capacities. The mix of these capacities in a community conveys how well it is positioned to absorb and adapt to natural hazards.
Exposure	refers to changes in essential climate variables (ECVs) which are defined as a physical, chemical, biological variable, or a group of linked variables that critically contributes to the characterization of Earth’ climate (54 ECVs in total[6])

Forest Fire Danger Index	indicates fire danger on a given day based on observations of precipitation, temperature, humidity, and wind speed
Green adaptation (ecosystem-based)	nature-based approach, sustainable management, conservation, and restoration of ecosystems
Hard adaptation	technological and engineering solutions
Risk Likelihood	a chance of a consequence taking place in the event of a hazard occurrence. A likelihood that a climate hazard will cause harm under a given scenario. It's important to note that we consider the probability of a hazard and consequence occurring under a given climate change scenario and not the probability of the climate event (in the context of climate risk assessment).
Representative Concentration Pathways (RCPs)	a set of time series of plausible future concentrations of greenhouse gases, aerosols, and chemically active gases, as well as land-use changes.
RCP8.5	is a high greenhouse gas emission scenario without effective climate change mitigation policies, leading to continued and sustained growth in atmospheric greenhouse gas concentrations
Residual risk	a risk that endures following adaptation and risk reduction efforts.
Resilience	resilience is defined as coordinated actions needed to increase the ability of assets, organisations and communities to cope with the effects of multiple shocks and stresses and how to minimise their economic, social, and environmental impacts.[7] It can also be defined as a capacity of interconnected social, economic, and ecological systems to cope with disturbances by reorganising in ways that maintain their essential function, structure and identity[8]
Risk owner	is a person who has been given the authority to manage a particular risk and is accountable for doing so[9]
Soft adaptation	physically intangible responses such as planning, policy, knowledge generation, management, and financial measures
Urban Heat Island Effect	localised warming due to urbanisation and the increase of dark surfaces (low albedo) such as roads, roofs, car parks and others.
Vulnerability	can be measured as the probability that an asset will fail given a climate impact

1. Guideline Objective

The following guideline has been developed to provide Transport for NSW (TfNSW), Project Teams, Alliance partners, contractors, and other TfNSW Stakeholders (external and internal) with practical "how-to" advice and requirements on conducting a Climate Risk Assessment (meeting the requirements of TfNSW Sustainable Design Guidelines DMS-ST-114). It can help identify climate change risks, assess potential consequence, likelihood and risk levels, identify adaptation strategies (risk mitigation), and create monitoring programs.

The developed framework can be used for planning and investment/options assessment. It enables climate change risk integration into TfNSW Risk Management and Asset Management Framework and Environmental Impact Assessment.

A review of project-specific climate risk assessments (CRA) submitted to TfNSW has informed the guideline, gap analysis and the feedback on version 3.2 of the TfNSW Climate Risk Assessment Guidelines. The review identified an overall lack of consistency in conducting CRA, a lack of reliable data analysis, insufficient technical background by those running the CRA, and inefficient and inadequate identification of risk levels within CRA workshops. This guideline seeks to apply a consistent approach and standard methodology to undertaking a Climate Risk Assessment in line with the TfNSW SDG requirements.

Development of this guideline has been prepared to align with a minimum of Level 2 compliance with the Infrastructure Sustainability Council of Australia (ISCA) Rating Tool Technical Manual Version 1.2 (Cli-1 and Cli-2) and 2.0 (Res-2) requirements for 'Design' and 'As Built' phases.

Multiple documents and standards have informed the development of this guideline. These include:

Table 1 Reference Climate Risk Guidelines and Standards

Organisation	Year	Document name
ISO Standard	2021	ISO 14091 Adaptation to climate change - Guidelines on vulnerability, impacts and risk assessment
Adapt NSW	2021	Climate Risk Ready NSW Guide
TfNSW Asset Standards Authority	2020	Technical Note – T MU MD 20002 ST
TfNSW Enterprise Risk Management Team	2020	TfNSW Enterprise Risk Management Standard
TfNSW Customer Technology and Services Division	2019	TfNSW Service Provider Asset Management Plan Standard

Organisation	Year	Document name
ISCA	2018	ISv2.0 Climate and Natural Hazards Risk Guideline
ISCA	2018	ISv1.2 Technical Manual
CSIRO	2018	Climate Compass: A climate risk management framework for Commonwealth agencies
TfNSW Asset Standards Authority	2017	Risk Tolerability, Quantified Risk Assessment and its Role in the Assurance of Change
CoastAdapt	2017	Guidance on climate change risk assessment
Sydney Trains	2015	Climate Change Risk Assessment and Adaptation Management Plan
ISCA	2015	Infrastructure Sustainability Rating Tool Technical Manual v 1.2: Cli 1 – Climate Risk Management
Green Buildings Council of Australia	2015	Green Star Communities v1 Submission Guidelines: Credit 04: Adaptation and Resilience.
Australian Standard	2013	AS 5334-2013 Climate change adaptation for settlements and infrastructure – A risk-based approach
Australian Greenhouse Office	2006	Climate Change Impacts & Risk Management A Guide for Business and Government

Also, consultation has been undertaken with key stakeholders from the following organisations to support alignment with existing industry standards and requirements:

- ISCA
- NSW Department of Planning, Industry and Environment
- Sydney Metro North West
- TfNSW Operations
- TfNSW Asset Management
- Asset Standards Authority

2. Introduction

2.1. Climate change overview

Globally average air temperature has warmed by over 1.2 ± 0.1 °C since records began in 1850 (based on 2020 data)[1]. Despite La Niña cooling conditions, 2020 was one of the three warmest years on record and the last decade is the warmest on record[10]. Increasing global mean temperatures and changes to the average climate system, driven primarily by higher carbon dioxide levels due to human influence[11], lead to higher frequency and intensity of extreme weather events globally and in Australia. Significantly, the projected recurrence and intensity of extreme weather events can occur much faster and have a more significant impact than changes to the average climate system state[5] (Figure 1).

The warming is not equally distributed around the globe; in Australia, the year 2019 showed 1.52°C above-average annual national mean temperatures[12] and NSW annual maximum temperature anomaly of 2.44°C[13] (Figure 2).

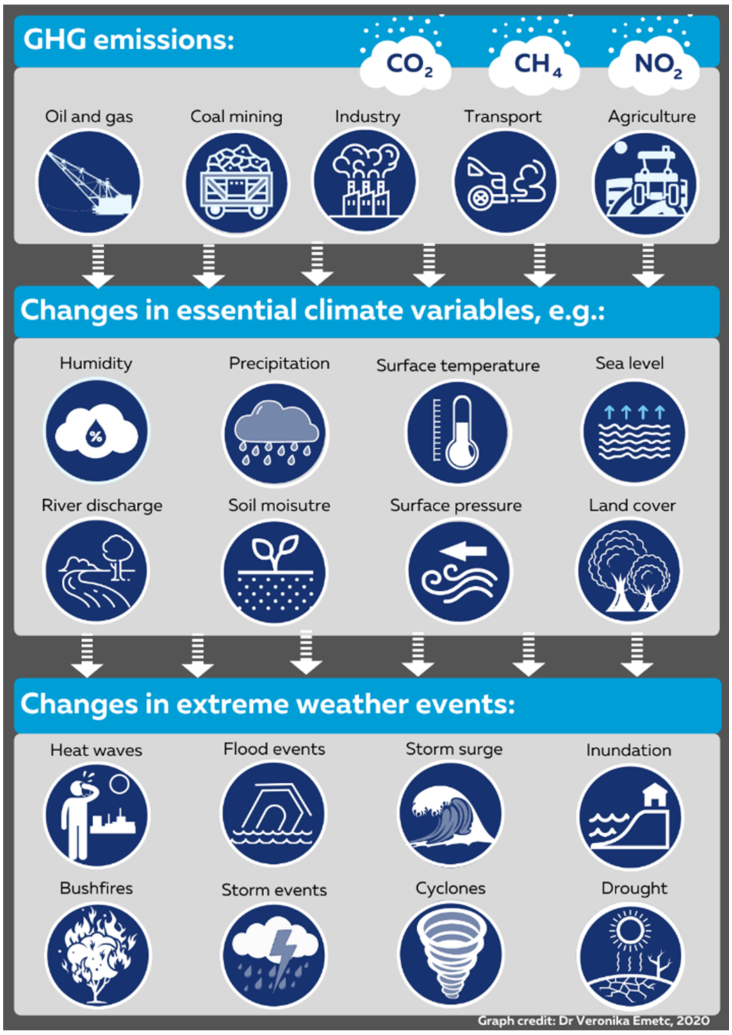

Figure 1 Relationship between climate variables and impacts

In Australia, nine out of the top ten warmest years ever recorded have occurred since 2005, with 2019 marking the warmest year on record for NSW. Penrith in western Sydney reached 48.9 °C on the 4th of January 2020, the highest observed in an Australian metropolitan area[10].

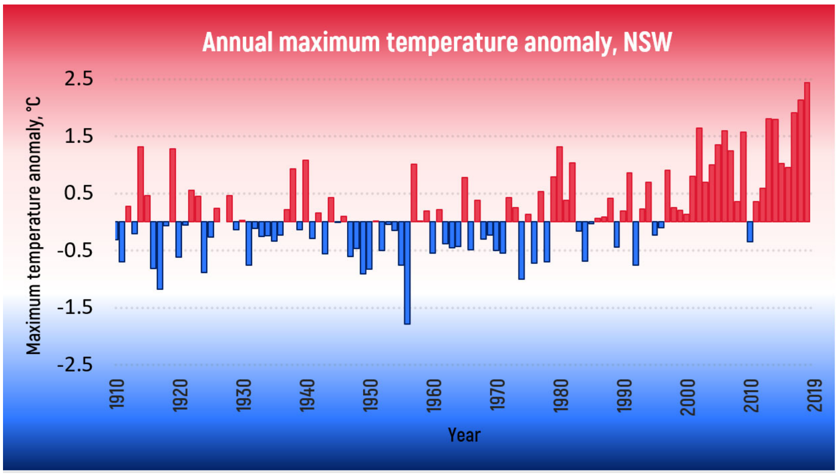

Figure 2 Annual maximum temperature anomaly in NSW for the period from 1910 to 2019 based on the Bureau of Meteorology climate data[9]

Changes to various climate variables can already be observed globally and in Australia, and the future changes are projected to be more significant. The current and future state of relevant climate extremes is shown in Table 2.

Table 2 Changes in extreme weather events

Extreme weather event	Changes observed to-date (since 1850)	Projected Changes (2020-2100)
Heatwaves	Meteorological records show that since the 1910s, the duration, frequency, and intensity of heatwaves have increased across many parts of Australia, including NSW. Heatwaves are also starting earlier in the year, and every year is now warmer than the range it would have been without human impact. There have been 33 days with temperatures exceeding 39°C (nation-wide) in 2019, which exceeds the numbers observed from 1960 to 2018 combined.	More heat extremes (both in frequency and intensity) are projected to take place in future[9].
Bushfires	In parallel with rising temperatures, over the past 30 years, the number of fire days and the fire season's length have increased across Australia since the 1950s. The fire season also starts earlier, with fire weather extending into spring and autumn throughout the state [14]. The year 2019 characterised by widespread severe fire weather	It is projected that a fire season in NSW will be longer in the future, and there will be more dangerous fire weather days[10]. Moreover, there is a significant trend towards more days with fire-generated thunderstorms, leading to hazardous fire conditions.

Extreme weather event	Changes observed to-date (since 1850)	Projected Changes (2020-2100)
	throughout the year, and the national annual accumulated Forest Fire Danger Index was the highest since 1950 when the national records began[11]. During the summer of 2019-2020, over 5.4 million hectares burned in NSW, which equates to 6.82% of the state – the worst on record[11].	
Extreme rainfall Flooding Landslides	The likelihood of the occurrence of extreme rainfall events is increasing, which results in increased flash flooding. In Australia, flooding events become more frequent and intense in recent decades[15]. Daily rainfall totals have increased, mainly due to an increase in the intensity of rainfall rather than an increase in the number of rainfall events. In February 2020, Sydney and the Illawarra region saw 392 mm of rainfall over four days, which is more rain than the total received in the second half of 2019[4]. Impacts from flooding and storm surges often result in widespread damage, loss of life, and environmental degradation.	The future short-duration heavy rainfall events are projected to increase[9]. Total rainfall in Australia is expected to increase by 7% per each degree of warming, and the increase of short-duration heavy rain is projected to be larger than 7%. Frequent short heavy rainfalls will lead to an increase in flash flooding, thus, significantly impacting road and rail assets. The impact can be even more significant considering urbanisation and, therefore, a decrease of run-off.[16]
Drought	In South-East Australia, there has been a 12% decline in April-October rainfall since 1990s[6].	Although the intensity and frequency of heavy rainfall events are projected to increase, the total amount of precipitation is projected to decrease (an increase of the time spent in drought)[9].
Sea level rise Storm surge	Global sea levels have risen by ~0.25 metres since 1880 and continue to grow. The sea level rise rate has also accelerated: from 1.5±0.2 cm/decade to 3.5±0.4 cm/decade. Sea level rise in Australia's southeast has been significantly higher than the global average [9].	The ongoing sea level rise will continue, and in future, it could be higher than previously projected (due to Antarctic ice sheet contribution). The extreme sea levels (caused by a combination of sea level rise, high tides, storm surges and waves) that previously occurred once every 100 years are projected to happen every year by mid-century (higher-emissions scenario) or by the end of the century (for the lower-emissions scenario)[5].

Extreme weather event	Changes observed to-date (since 1850)	Projected Changes (2020-2100)
		It is projected that the impact on road and rail assets will increase significantly once sea level rise reaches 0.5 metres (IPCC 2014).[17]
Cyclone Extreme wind	There has been a decrease in the number of tropical cyclones in Australia since 1982[14].	There will be a larger proportion of higher-intensity tropical cyclones in the future[14].
Lightning	Climate change can lead to more intense and damaging storms[i]. There is less evidence for a change in recent decades owing to the large year-to-year variability[18].	The projections suggest a 30% increase in the frequency of conditions favourable to severe thunderstorms (including hailstorms) by 2100[18].
Hail	Current hail hazard is poorly quantified in most regions of Australia.	There are projected to be more hail events per decade in East Australia, resulting in a 40% relative increase in hail frequency and a greater number of extreme events[ii].
Compound extreme events	When multiple types of extreme weather events coincide, it can result in severe conditions or a 'cascading effect'[9]. For example, heat waves combined with drought conditions can have a more damaging impact.	Background climate trends can amplify natural climate variability, and compound events can have a more significant impact in the future.

2.2. Why consider climate risks

Climate change creates a significant risk to infrastructure, people, and the economy. Future climate change risks depend on the rate and duration of global warming, which depends on reducing CO2-e. If governments do not reduce global emissions sufficiently (by about 45% from 2010 levels by 2030) to keep the warming under 1.5˚C, the impacts can be long-lasting or even irreversible[20].

"Australia is among the developed countries most vulnerable to climate change. Our climate is highly variable and predisposed toward extreme weather events, and our ecosystems are finely balanced and often unique. Most of the country's population lives in coastal cities exposed to rising sea levels and connected by infrastructure exposed to the full range of weather conditions. Climate change will have direct economic costs for Australia that need to be managed."[21]

An increasing number of extreme weather events is already a risk to our Transport assets and network. The Reserve Bank of Australia (RBA), Australian Prudential Regulation Authority (APRA), and Australian Securities and Investments Commission (ASIC) all recognise climate change as a material economic risk to the Australian economy. Between 1967 and 2013, New South Wales recorded the highest losses associated with disasters among all states[22]. The total financial cost of natural disasters in New South Wales already accounts for $3.6 billion per year (Figure 3), with flood accounting for 23% of this cost and 66% due to storm and hail damage (49% and 17%, respectively)[23]. The total economic cost of natural disasters will reach $10.6 billion a year in NSW and $39.3 billion a year in Australia by 2050, a growth rate of 3.4% per year[7]. In fact, in 2019-2020, this number was even higher, accounting for $110 billion of total damage and economic loss due to bushfires[24]. According to the recent report by Deloitte Access Economics[26], in the absence of action, climate change will cost NSW a 4% reduction in gross state product and a 2% loss in employment by 2070.

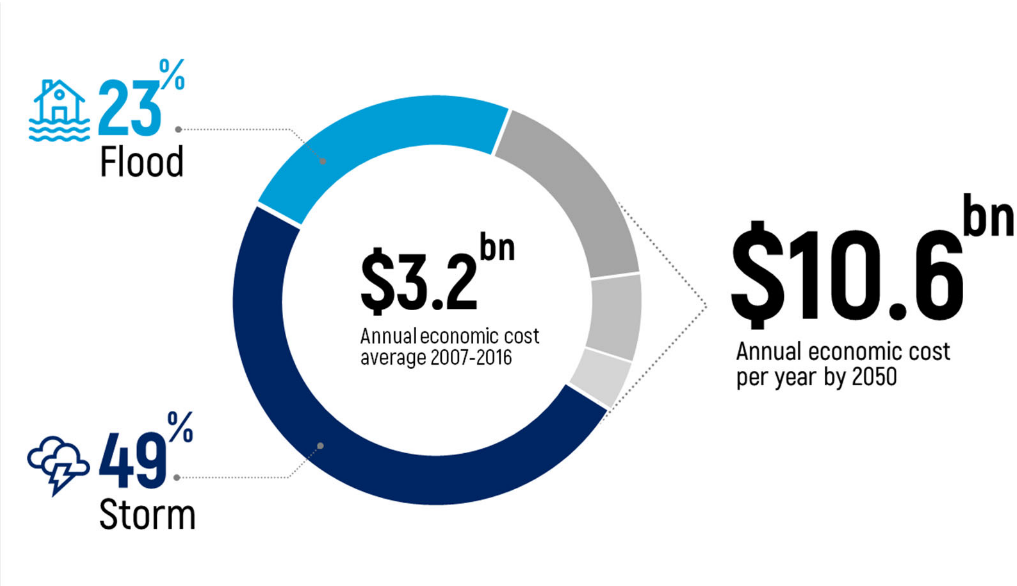

Figure 3 The financial impact of natural disasters in NSW per year (adapted from Deloitte Economics, 2017).

The Commonwealth Corporations Act 2001 requires listed companies to disclose risks that may impact investors or financial performance. The Australian Securities and Investments Commission (ASIC) has stated that companies should consider climate change in internal risk assessment and provide meaningful climate risk disclosure to external stakeholders. ASIC has also indicated that company directors and officers must understand and continually reassess relevant climate change risks. According to the Centre for Policy Development "directors of public authorities will be duty-bound to exercise due care and diligence in relation to foreseeable risks" [25] and "public sector directors are now increasingly likely to be closely scrutinised and held to account for climate risk management"[24] .

Most of the Transport assets have a long design life. However, the traditional design approaches based on historical weather records are no longer valid regarding future risks associated with climate change.[26] According to Deloitte Access Economics 2020[27], the transport sector is likely to experience increasing demand and require significant industry change.

Managing climate change risks and opportunities is our duty as public servants. TfNSW has an obligation under NSW and national legislation and responsibility under the Rail Safety National Law 2012 to guarantee the safety of our assets and operation SFAIRP. Moreover, TfNSW must ensure that the health and safety of workers or other persons are not put at risk from the work undertaking, according to the Work Health and Safety Act 2011. The Maritime Safety (Domestic Commercial Vessel) National Law Act 2012 places a duty to ensure SFAIRP the safety of the vessels and operations (applicable to ferries). The ST-006 Safety Change Management Standard places requirements on TfNSW to support our assets' safety assurance through the asset life cycle.

It is critical to understand that the whole-of-life cost of inaction will more likely overcome the cost of adaptation and resilience measures[28 29].

Addressing climate risk and resilience is highlighted in legislation, Federal and State Government policies, and Strategies and guidance, as highlighted in Table 3.

Table 3 Legislation, Federal and State Government policies, as well as Strategies and guidance *that include climate change action*

Legislation		
Document	**Year**	**Climate change action**
Government Sector Finance Act (NSW) (GSF Act)	2018	States that all New South Wales Government agencies and entities must systematically identify and manage risks to mitigate negative impacts and maximise opportunities for the New South Wales Government and community.
Fiscal Responsibility Act (NSW)	2012	Climate risk management supports the Act's principles and objectives in helping to maintain the AAA credit rating of the State of New South Wales.
Policy		
Document	**Year**	**Climate change action**
Net Zero Plan Stage 1: 2020–2030	2020	The plan outlines how emissions reduction mitigation measures benefit from creating a more resilient and sustainable economy and communities.
Asset Management Policy for the NSW Public Sector (TPP 19-07)	2019	The policy states that Asset Management Plans should include “an assessment of the resilience and vulnerability of the agency’s assets to the impacts of climate change … and proposed mitigations/interventions”.

The Internal Audit and Risk Management Policy for the General Government Sector (TPP20-08)	2018	Under Core Requirement 1.2, the policy requires organisations to consider emerging risks such as climate-related risks when assessing risks that might prevent an organisation from achieving its objectives.
NSW Gateway Policy (TPP 17-01)	2017	Whilst climate risks are not explicitly considered under Treasury's Recurrent Expenditure Assurance Framework (TPP 19-03), considering climate risks through an assessment may help inform project risk assessment requirements for recurrent major projects.
NSW Climate Change Policy Framework	2016	A key objective is to make New South Wales more resilient to a changing climate: • Assess and effectively manage climate change risk to government assets and services. • Reduce risks and damage to public and private NSW assets arising from climate change. • Reduce climate change impacts on health and wellbeing • Manage impacts on natural resources, ecosystems, and communities
Critical State Significant Infrastructure Standard Secretary's Environmental Assessment Requirements (SEARs)	2015	The policy requires all projects to be "designed, constructed and operated to be resilient to the future impacts of climate change." "The Proponent must assess… the impacts on flood behaviour during construction and operation for a full range of flood events... taking into account sea level rise and storm intensity due to climate change." "The Proponent must quantify specific climate change risks with reference to the NSW Government's climate projections at 10km resolution."
Strategies and Guidelines		
Document	**Year**	**Climate change action**
Climate Risk Ready NSW Guide	2021	The guide is developed to help New South Wales Government sector agencies better understand their exposure to climate-related risks, address material risks and opportunities, and embed climate risk management into existing risk management frameworks.
National Emergency Risk Assessment Guidelines (NERAG) Handbook	2020	This handbook establishes a nationally consistent approach to emergency risk assessment and includes considering climate change impacts.
NSW Critical Infrastructure Resilience Strategy	2018	Promotes improving infrastructure, organisational and community resilience. The strategy's scope includes natural, technological and malicious hazards and focuses

		on improving adaptation to long-term stresses such as climate change.
National Climate Resilience and Adaptation Strategy	2015	Identifies a set of adaptation measures to mitigate climate change risks. It's an outline of the government vision of a climate-resilient future.
This United Nations Office for Disaster Risk Reduction (UNDRR) framework	2015	It recognizes that the State has the primary role in reducing disaster risk, but that "responsibility should be shared with other stakeholders, including the local government, the private sector, and other stakeholders". It provides a roadmap for making our communities safer and more resilient.
Climate change adaptation for settlements and infrastructure - A risk based approach (AS 5334-2013)	2013	Guides managing climate change risks to infrastructure and include implementation plans for effective adaptation (risk treatment).
TfNSW documents		
Document	**Year**	**Climate change action**
TfNSW Environment and Sustainability Policy	2020	Outlines a collective commitment to delivering environmental and sustainability outcomes across the Transport cluster, outlining the methodology Transport for NSW will use to meet its commitments to economic prosperity and social inclusion in an environmentally responsible and sustainable manner. One of the key themes is resilience – embedding climate risk and resilience considerations in our activities
Future Transport Strategy 2056	2020	Identifies 'managing a resilient transport system' as a key outcome and acknowledges that "transport assets have long economic lives and are vulnerable to the direct impacts of climate change".
Environmental Sustainability Strategy 2019-2023	2019	Objective to embed resilience and climate change adaptation options into the design and construction: • assess climate change risks for all potentially affected projects and programs • address all identified climate change risks ranked as high or above during project planning
TfNSW Sustainable Design Guidelines	2017	One of the aims of the guideline is developing, expanding, and managing a transport network that is sustainable and climate-resilient. The delivery mechanism for implementing TfNSW's sustainable project delivery requirements, the SDG requires the completion of a climate risk assessment.
NSW Long term Transport Masterplan	2014	The plan identifies responding to climate change as a "state-wide action of priority". Action 8.8.3 focuses on

		boosting our resilience to climate change and natural disasters by assessing climate resilience.

Recognising that climate change's effects pose a significant risk to our business, infrastructure assets, and the communities it serves, TfNSW is committed to improving climate change resilience across its network for all old and new assets (including the community). To do this, TfNSW requires a reliable assessment of weather-related risks and the associated monetary and non-monetary impacts on our assets and a selection of adaptation measures that can reduce the identified risks. Also, critical interdependencies of other types of transport, energy, water, and telecommunications infrastructure need to be understood and managed.

The methods that have long been used to inform project designs are increasingly being inadequate at helping understand the level of risk and potential impact resulting from climate change. One way of addressing these risks and uncertainties is by identifying measures to adapt and build resilience through a climate risk assessment.

2.3. When and who should undertake CRA

There are several opportunities to address climate risk across a project's life cycle, and the focus of this guideline is to align different stages of CRA to different project stages. Climate Change Risk Assessment should be initiated as early as possible in the project life cycle. By doing so, it is more likely that projects can successfully implement necessary climate risk mitigation measures and achieve the most benefit. The CRA process also needs to align with the NSW Gateway Policy, and Infrastructure Investor Assurance Framework (IIAF) applied to all projects with a value of over $10 million.

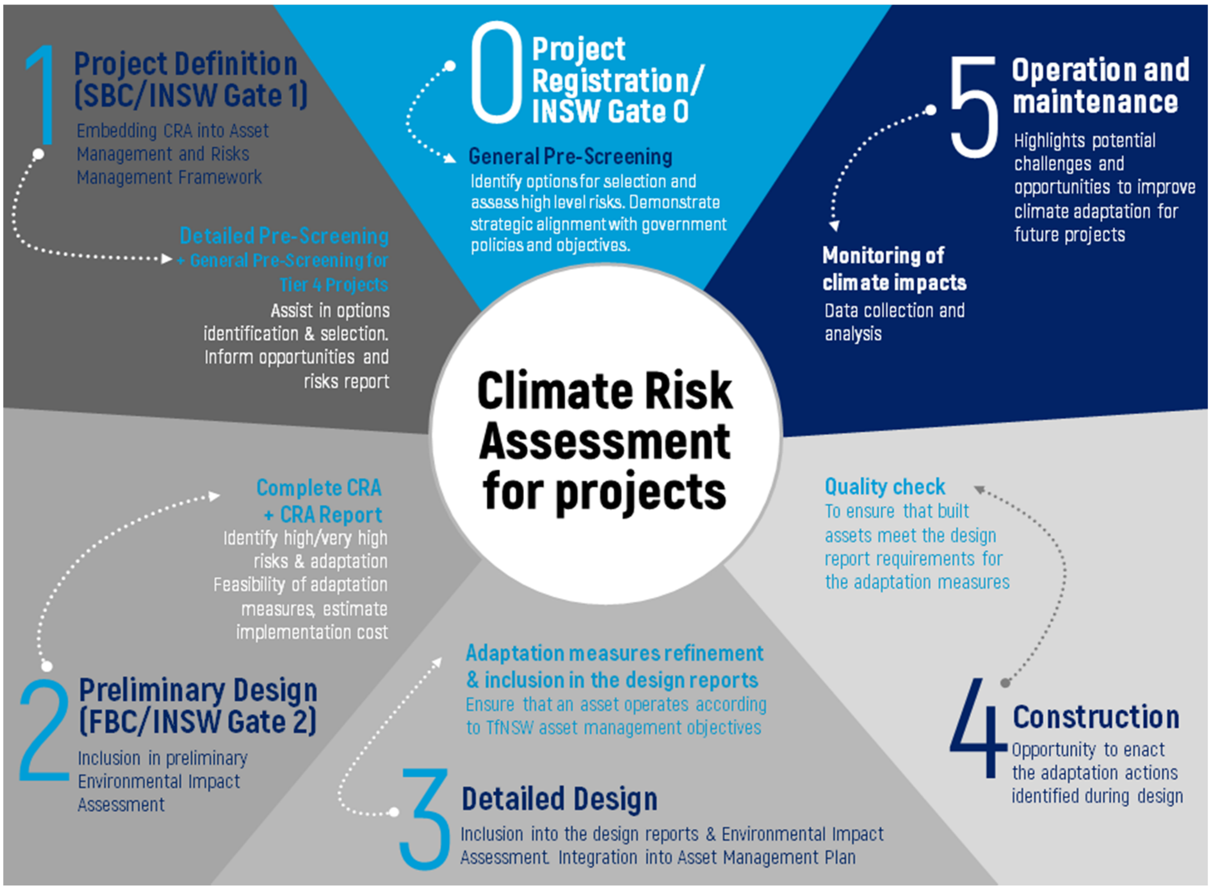

Figure 4. Climate change risk assessment at project lifecycle and deliverables

This approach can enable projects to bring clarity and structure to the CRA process. It can start with General CRA Pre-Screening, where the overall number of climate change risks is identified for each project location. This can be followed by a detailed CRA Pre-Screening, which includes identifying the number of climate risks for all relevant asset types/disciplines in each project location. Once the Pre-Screening process is complete, it needs to be followed by a complete CRA (Figure 4 and Table 4). A facilitated risk assessment workshop is recommended for refining and finalising a CRA.

Table 4. Climate change risk assessment at project lifecycle and INSW Gates

Phase	Project Stage	CRA Stage
Development	**Project Registration & INSW Gate 0**	All projects must pass INSW Gate 0[30]. "The Review informs the delivery agency's decision to allocate resources to progress the project through to an analysis of options and Strategic Business Case"[28]. At this stage, the General CRA Pre-Screening:

		• can provide evidence of problem or service needs (e.g. asset/location needing upgrades/resilience actions due to high climate risks) • demonstrate alignment with strategic government policies and objectives (that include climate change adaptation and resilience) • assist in completing an Investment Brief by identifying high-level planning risks. • can help to inform site or route selection and to analyse a range of options at Gate 1 or SBC project stage
	SBC & INSW Gate 1	One of the key focus areas of Gate 1 is risk management and social, economic, and environmental sustainability, which includes resilience to climate change. Thus, climate change risks need to be included in Risk Management. Conducting detailed CRA Pre-Screening at this stage can enable the project team to integrate it into the Asset and Risk Management Framework. Results of both general and detailed CRA Pre-Screening can help inform options selection, ensure maximum benefit at optimal cost and identify preferred pathway and scope.
	FBC & INSW Gate 2	INSW Gate 2 requires ‘ongoing identification and active management of risks and opportunities using a structured and formal methodology’. At this stage, a complete CRA can identify risks, risk treatment, and estimate the feasibility of adaptation measures. Complete CRA can also provide an opportunity to conduct a high-level estimation of implementation cost. It is essential to finalise a complete CRA by the end of this project stage to ensure enough funding is allocated to implement adaptation measures. Complete CRA can be conducted in three stages: identifying risk statements, assessing risk levels and selecting adaptation measures (calculation of residual risk levels). Identified risks and adaptation measures then can be added in a preliminary Environmental Impact Assessment.
Deliv ery	**Detailed Design**	At a Detailed Design stage, identified risks and appropriate adaptation measures (identified at former stages) should be included in the design report, integrated into Asset

		Management Plan and Environmental impact assessment. Central to the task is, identifying and assessing the risks climate change poses to TfNSW projects and prioritising those risks that require appropriate actions for adaptation.
	Construction	CRA objectives include delivering the design, implementing adaptation measures and ensuring that built assets meet design report requirements. It is necessary to continue reviewing and updating the risk register during this project stage.
Operation	**Operation and Maintenance**	Following Risk Management Process (ISO 31000:2018), monitoring and review are required at the last step of the risk assessment process. This approach enables evaluating risk treatment effectiveness and is critical to ensure continuous improvement. This step includes monitoring risks treatments and climate change trends and impacts. If new data becomes available, it needs to be accounted for in the risk register. Overall, it is essential to keep in mind that the risk register needs to be a dynamic document that gets regular updates (at least annually).

Climate Risk Assessment should be prepared by a relevant professional who has completed climate-related training including a tertiary degree in Environmental or Earth Sciences, or equivalent, has a good understanding of climate modelling, and experience in risk assessment. We recommend using the TfNSW CRA eligibility checklist.

As a minimum, the person leading the CRA's qualifications and suitability should be submitted through a memo to the relevant TfNSW Senior Manager Sustainability for approval before undertaking the assessment. Once the CRA has been completed, it should be forwarded to the TfNSW Senior Manager Sustainability, or delegate, for review and to the Project Director to accept. The CRA should be submitted before the completion of the 30% design or equivalent stage.

Regardless of the capital value, it is best practice to consider risks and opportunities throughout the life cycle. Therefore, we recommend using project risk level rather than the capital value alone when evaluating the need to undertake a CRA. All projects should undertake at least the general CRA pre-screening. Notably, the pre-screening has to be project-specific and based on the location-specific climate data (rather than average over the East-Coast or NSW).

2.4. How to undertake CRA

Climate Risk Assessment needs to include three stages:

- Preparation for CRA (Pre-screening during this stage)

- Complete CRA and conducting CRA verification with relevant stakeholders
- Post-CRA reporting, implementation of adaptation measures and monitoring

The overall process can be divided into ten critical steps, as shown in Figure 5. The process's general structure aligns with ISO 31000Risk Management Standards, ISO 14901:2021 Adaptation to climate change - Guidelines on vulnerability, impacts and risk assessment and Climate Risk Ready NSW Guide (following the overall process structure of risk identification, risk analysis, risk evaluation, risk treatment, risk monitoring and review). The process needs to be conducted in communication and consultation with relevant stakeholders. A participatory approach is essential in most assessment phases to ensure the delivery of a high-quality assessment (ISO 14901:2021).

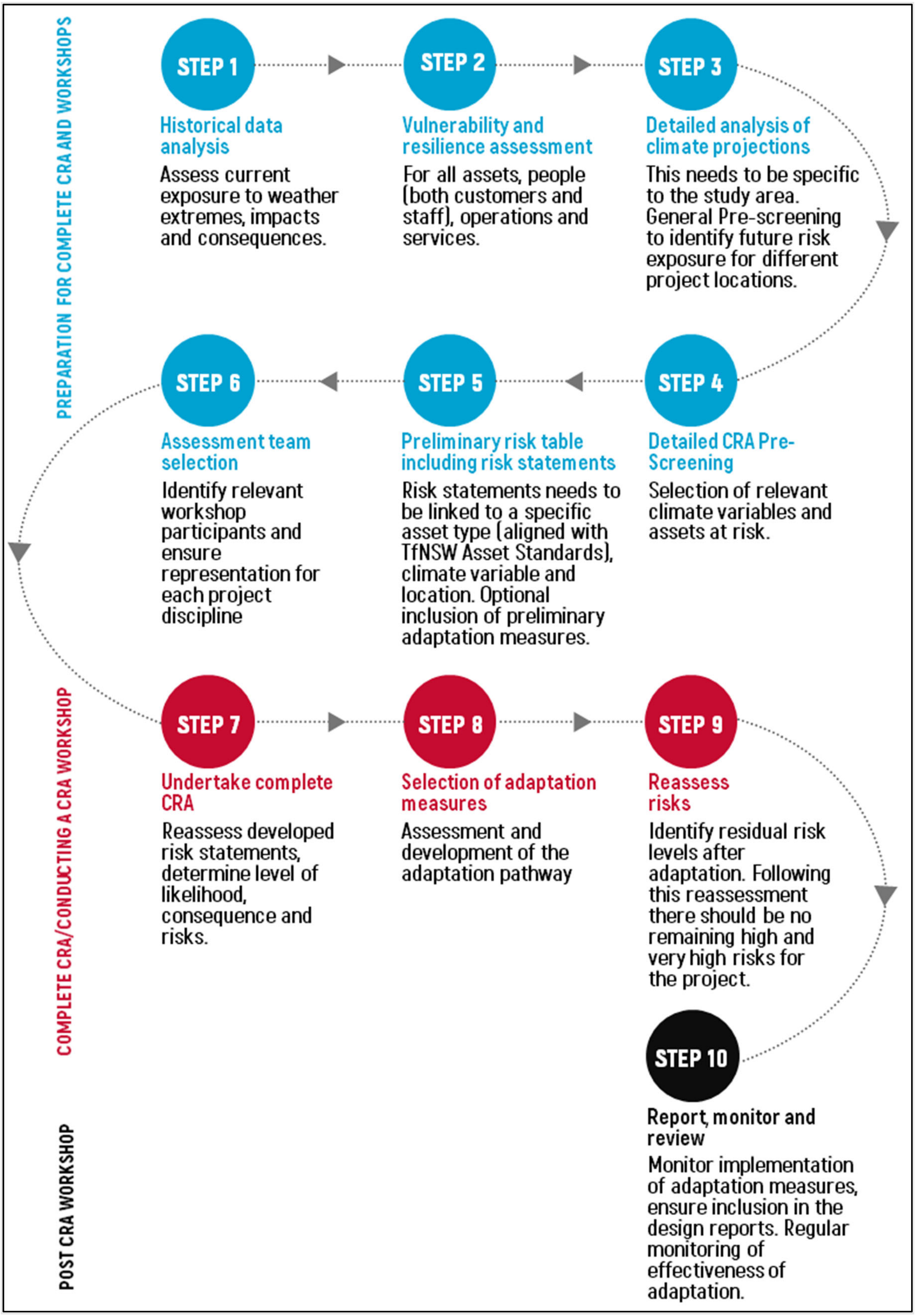
PREPARATION FOR COMPLETE CRA AND WORKSHOPS
STEP 1
Historical data analysis
Assess current exposure to weather extremes, impacts and consequences.
STEP 2
Vulnerability and resilience assessment
For all assets, people (both customers and staff), operations and services.
STEP 3
Detailed analysis of climate projections
This needs to be specific to the study area. General Pre-screening to identify future risk exposure for different project locations.
STEP 4
Detailed CRA Pre-Screening
Selection of relevant climate variables and assets at risk.
STEP 5
Preliminary risk table including risk statements
Risk statements needs to be linked to a specific asset type (aligned with TfNSW Asset Standards), climate variable and location. Optional inclusion of preliminary adaptation measures.
STEP 6
Assessment team selection
Identify relevant workshop participants and ensure representation for each project discipline
COMPLETE CRA/CONDUCTING A CRA WORKSHOP
STEP 7
Undertake complete CRA
Reassess developed risk statements, determine level of likelihood, consequence and risks.
STEP 8
Selection of adaptation measures
Assessment and development of the adaptation pathway
STEP 9
Reassess risks
Identify residual risk levels after adaptation. Following this reassessment there should be no remaining high and very high risks for the project.
POST CRA WORKSHOP
STEP 10
Report, monitor and review
Monitor implementation of adaptation measures, ensure inclusion in the design reports. Regular monitoring of effectiveness of adaptation.

Figure 5 CRA step-by-step process

3. Preparation for Complete CRA

3.1. Step 1: Historical data analysis

3.1.1. Current climate risk exposure

Exposure describes elements that are at risk from a hazard. It is essential to keep in mind that if a location is not exposed to extreme weather today, it could become at-risk in future due to changing climate conditions. Therefore, this step should be treated with caution and performed only to estimate the current exposure to climate impacts – not future exposure. Nevertheless, information about the current exposure to extreme weather impacts is important in helping CRA participants identify the level of likelihood of specific climate impacts and ensure that the assessment is evidence-based rather than subjective. Moreover, determining the extent to which weather extremes may have already impacted the project site can draw attention to corresponding climate variables.

The number of the most significant natural disasters since 1939 is shown in Figure 6. This figure doesn't provide information on the upward trend in the number of disasters but can be used for general knowledge of background extreme climate events in NSW.

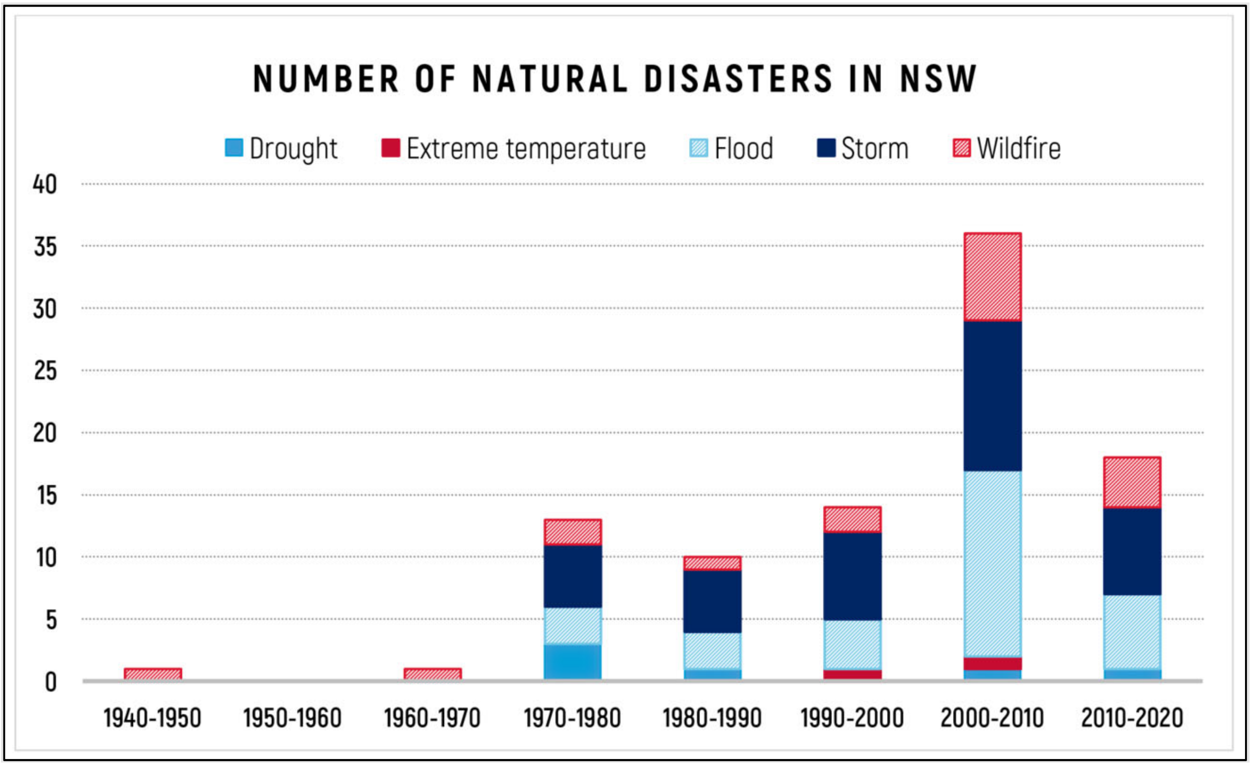

Figure 6 Number of natural disasters in NSW (climate-related) since 1939 based on EM-DAT dataset[31]

3.1.2. Impacts

Obtaining information about the impacts that extreme weather events already have posed on the infrastructure, environment, and people is critical for CRA preparation. Having an understanding of past climate impacts can help to select and develop more appropriate risk statements. Also, knowing how many times a specific impact has happened in the past is critical for estimating the likelihood levels. It is essential to demonstrate that climate change risks are not a matter of the distant future, and extreme weather already severely impacts the network.

The historical impacts assessment needs to include any geographical location in Australia and should not be limited by NSW only. This assumption is relevant because hot and wet future conditions in Sydney are likely to be similar to the conditions in Queensland: Tewantin-Noosa, Nambour, Maroochydore, Caloundra, Caboolture and Gold Coast[32].

Historical impacts of extreme weather on transport assets are shown in Appendix 6. This should be used as an example only as a more thorough analysis of the past effects is required. Extensive information about past impacts on Sydney Trains can be found in the Sydney Trains Climate Change Risk Assessment and Management Plan[33].

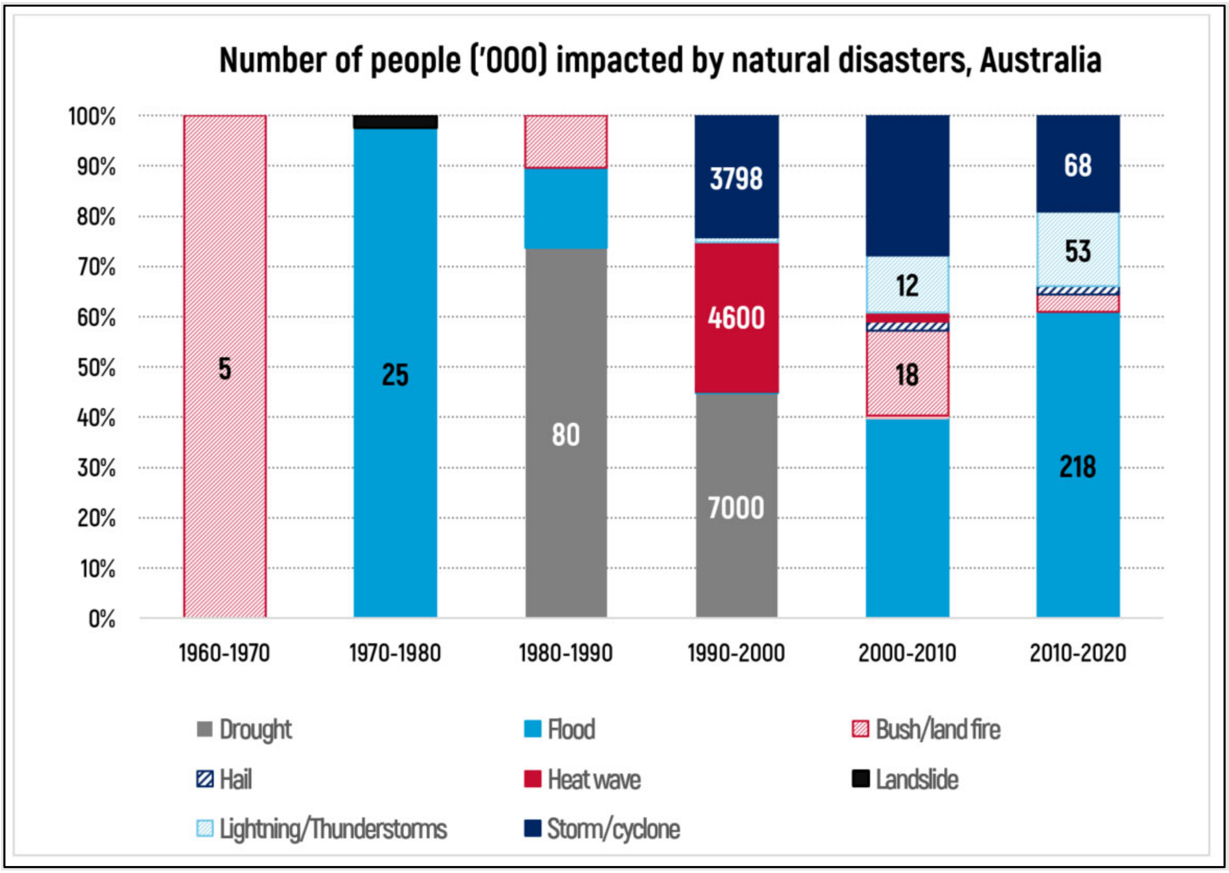

Figure 7 Percentage of contribution to the impact (injury, loss of property, homelessness) on people in Australia by a natural hazard type, based on EM-DAT dataset[28]

Moreover, extreme weather can impact not only assets but communities. When assessing climate risks, it's crucial to keep in mind that not only risks to physical assets need to be included, but also risks to communities and the environment. The number of people impacted by natural disasters since 1960 is shown in Figure 7, showing the type of disasters that had the most impact on people in terms of injuries, homelessness and loss of property between 1960 and 2020. The number of disaster-related deaths is shown in Figure 8.

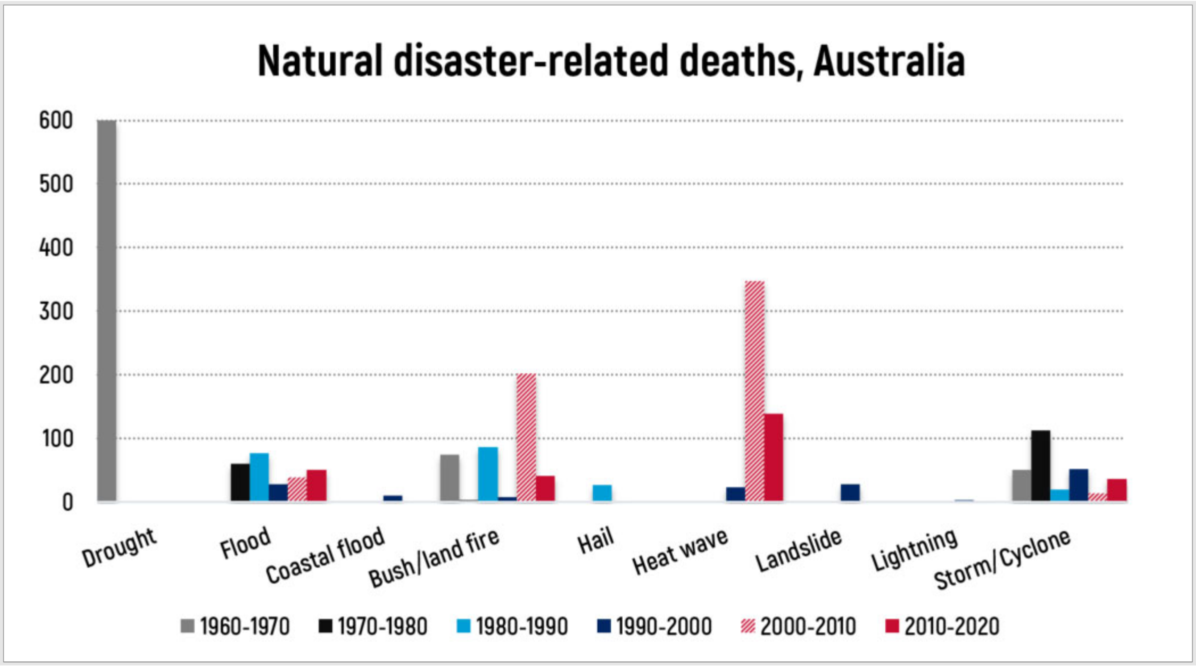

Figure 8 Natural disaster-related deaths in Australia since 1960, based on EM-DAT dataset[28].

Overall, past impact information sources may include:

- Any modelling that was undertaken for the project during early project planning, e.g. flood modelling, bushfire risk, drainage designs
- Rail safety investigations and reports by Australian Transport Safety Bureau
- Marine safety investigations and reports by Australian Transport Safety Bureau
- TfNSW can assist in providing this information, including technical studies undertaken as part of an Environmental Impact Statement (EIS), e.g. Review of Environmental Factors
- Media reports
- Sydney Trains Climate Change Risk Assessment and Management Plan
- Warnings and updates provided by the relevant local government authority
- Past incidents, insurance data

- International examples can be included to assess possible links between climate extremes and potential impacts (e.g. Europe flood in August 2002 resulted in electricity failures, disconnected telecommunication links, damage to roads and bridge structures, disruption to the gas service and contamination of clean water with floodwater)

3.1.3. Consequence

Another critical aspect of CRA is the estimation of a consequence of the climate change impact/hazard. This CRA's element is essential because it highlights the importance of identified risks. The description of the consequences must be relevant and quantified (if possible) to give this element meaning in real terms. It is essential to distinguish the consequences from impacts. For example, an impact is rail buckling due to heat, while the consequence is a possibility of train derailment, leading to deaths, financial implications, etc.

Overall, consequences can be tangible and intangible as well as direct and indirect. The "intangible" effects are those costs of natural hazards that do not have a market value[34] and are not, or at least not directly measurable in monetary terms (e.g. impacts on health, cultural heritage or the environment)[35]. . Direct consequences include directly quantifiable losses (e.g. a number of people affected or a number of damaged assets). In contrast, indirect consequences arise from the flow of goods and services (e.g. declines in revenue output, stress).[36]

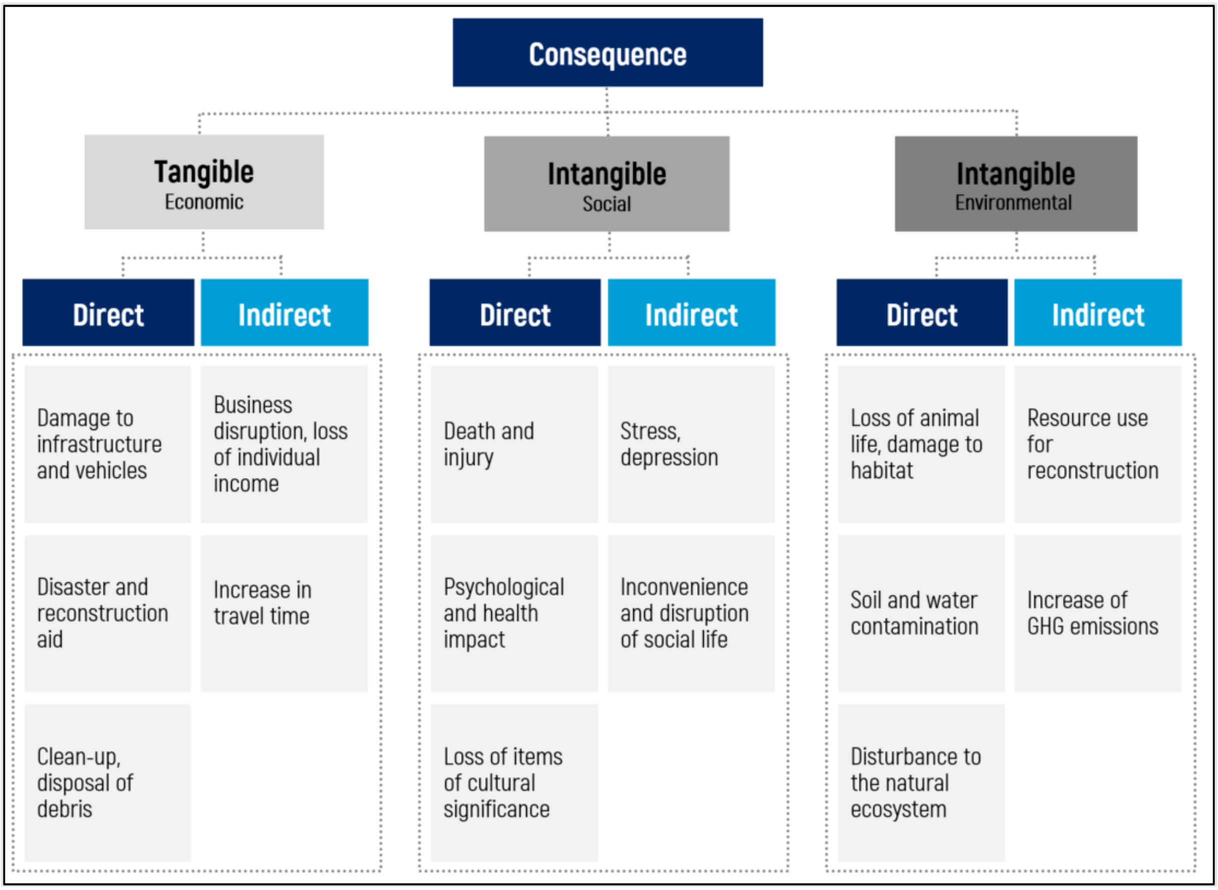

Figure 9 Consequence types

We recommend analysing a proportion of weather impacts related to each type of consequences. An example of the impacts on 'delays' is shown in Figure 10, demonstrating that the largest proportion of Sydney Trains' delays was related to rain, wind and storm (based on 2015 data)[37].

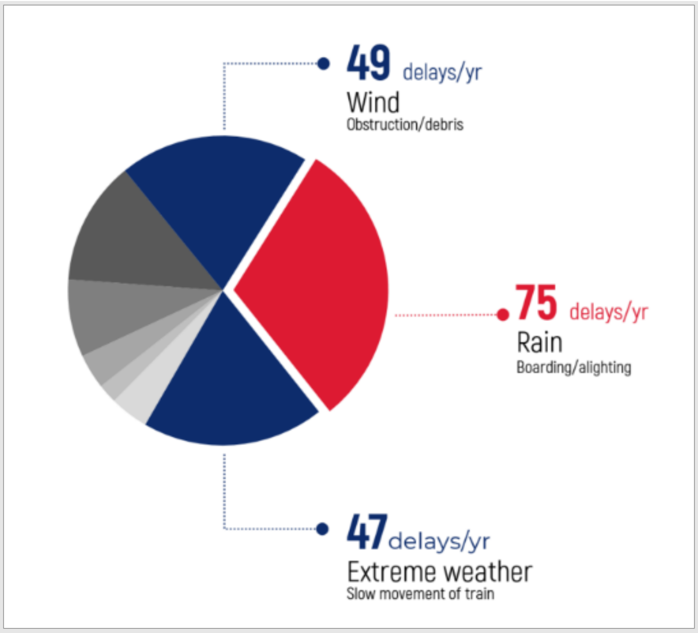

Figure 10 The number of rail delay incidents per year due to extreme weather events (based on 2015 data)[41].

3.2. Step 2: Vulnerability and resilience assessment

The level of risks that climate change poses on people depends not only on the magnitude of climate change but also on the communities' resilience and vulnerabilities. Therefore, CRA needs to consider information about vulnerability and resilience specific to the area.

Heat Vulnerability Index (HVI) shows NSW areas where people are more vulnerable to urban heat island impacts based on exposure, sensitivity, and adaptive capacity. The index ranges from 1 to 5, where 0 represents low exposure, low sensitivity and high adaptive capacity, whereas 5 represents high exposure, high sensitivity and low adaptive capacity (Figure 11).

The Australian Disaster Resilience Index assesses disaster resilience using factors that encapsulate the resources and abilities to “prepare for, absorb and recover from natural hazards” [38] (Coping Capacity), or enable learning, adaptation and problem solving (Adaptive Capacity). It is based on Social character, Economic capital, Emergency services, Planning and the built environment, Community capital, Information access, Governance and leadership, Social and community engagement (Figure 12).

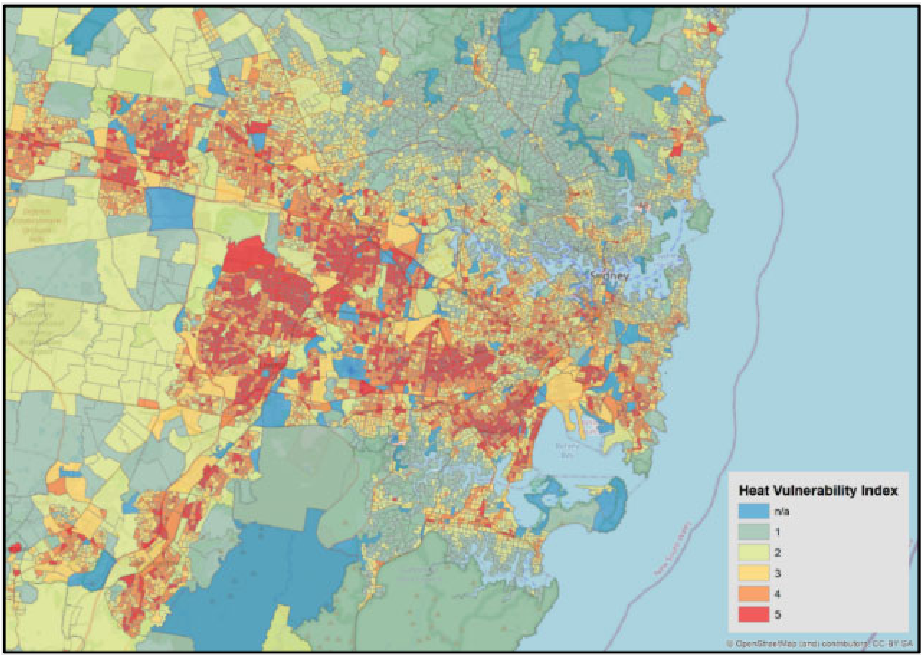

Figure 11 Heat Vulnerability Index for Sydney GMA in 2016 based on SEED dataset[38].

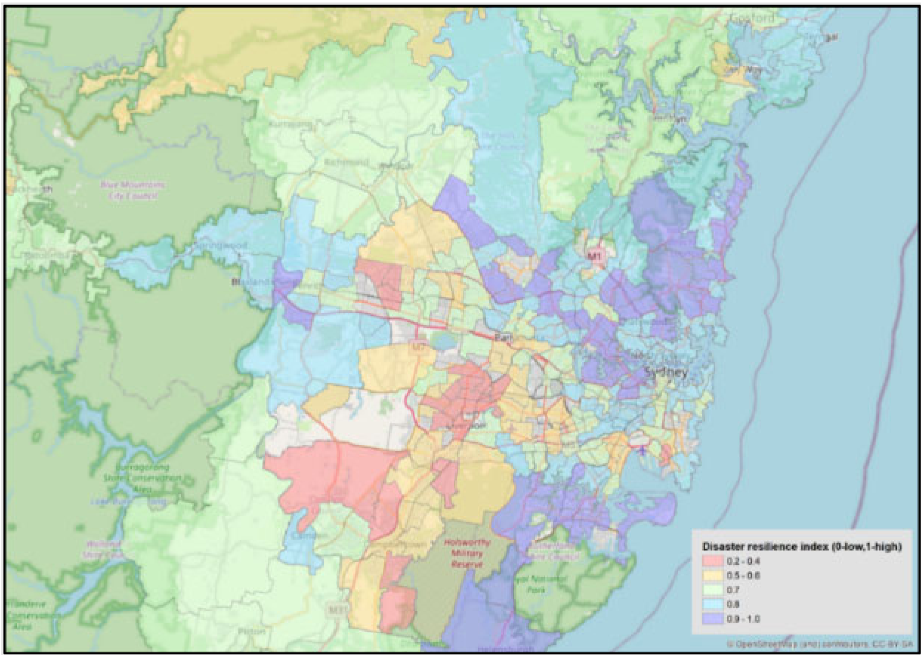

Figure 12 Disaster. resilience Index for Sydney GMA in 2016 based on Australian Disaster Resilience Index dataset[38].

Example of available data sources:

- SEED (data on heat vulnerability per SA1 statistical area for NSW[33])
- Bushfire & Natural Hazards (data on disaster resilience index[39])

Currently, these data sets are only available for 2016, and if more recent data becomes available, it should be used instead. Both websites allow downloading of the data sets, and it's highly recommended to download the data to extract location-specific information (versus just using the online map).

3.3. Step 3: Detailed analysis of climate projections

The future extreme weather impacts are likely to be more severe than it has been in the past, and the current design and construction standards might not be able to mitigate future climate risks. Therefore, it is insufficient to evaluate climate change risks based on past weather and historical data alone. An assumption that an asset is at low risk because it has been the case in the past can result in underestimation of the future risks and a consequent failure of the asset. Therefore, it is essential to conduct a careful analysis of climate projections.

3.3.1. Climate models

A climate model is a mathematical representation of a climate system. Due to computing restraints, the resolution of the global climate models is about 200 km, which makes them unsuitable for evaluating the local climate risks. Therefore, regional climate models (RCMs) have been developed to help government, businesses, and communities build resilience in the face of future extreme events and hazards by assisting them to understand regional climate change. They infer large-scale resolution models into a finer local scale using specific downscaling techniques (generally change factor methods, statistical downscaling or dynamic downscaling).

There are two RCM models available for Australia: NARCliM (NSW and ACT Regional Climate Modelling) and CSIRO (Commonwealth Scientific and Industrial Research Organisation) models. There are advantages and disadvantages of using these two models, and the best outcome can be achieved by incorporating both models into the analysis of future climate impacts.

- **Adapt NSW and NARCliM version 1.0**: NSW / ACT Regional Climate Modelling (NARCliM, 2014)[40]: Projections built by combining projections from four CMIP3 GCM models and downscaling them using Weather Research and Forecasting model (WRF) to a 10 km resolution for south-east Australia and 50 km resolution for the rest of Australia. There are three downscaling methods for each of the four GCM models, thus, providing 12 different projections. Available through Adapt NSW data portal.
- **CSIRO - Climate Futures**: Projections built by CSIRO and BoM (2015) using a combination of projections from 12 CMIP5 global climate models and downscaling them to a 25 km resolution[41].

A comparison of the above models' key components is shown in Appendix 4.

All climate models are tested to validate their accuracy using hindcasting – validating that they correctly model the past climate. It is important to note that although the suggested climate projections and the models are based on the most up-to-date climate research and are a reliable indicator of climate change, each model has a range of uncertainty. There are three main sources of uncertainty in projections of climate:

- Scenario uncertainty and the actual trajectory of anthropogenic GHG emissions
- Internal climate variability
- Uncertainties about feedback processes that affect changes in greenhouse gas concentrations in the atmosphere

Future climate changes may thus be *more* or *less* extreme than described in the models recommended for use in this guideline. However, it is crucial to keep in mind that although there is a need to consider a broad range of future climate scenarios when trying to understand the future climate, this does not apply to running a CRA. When conducting a CRA it is essential to look at the projections' higher end to ensure that risks are not underestimated.

3.3.2. Selection of climate variables

The first step in a CRA is confirming the nature of climate risk posed to the project by establishing the project context and identifying all relevant climate variables (e.g. temperature, rainfall, storminess). To understand which variables are likely to impact the project, an analysis of the climate projections for all climate variables is required.

Identifying the relevant climate variables is an essential step in preparing a CRA. Projected climate impacts in NSW that are most relevant for Transport assets are presented in Table 1. However, most of these parameters are not directly available from climate models, and indicators are used instead (e.g. temperature, precipitation). Indicators are used when states or conditions are not directly measurable (ISO 14901:2021).

When conducting a CRA, it is essential to understand that selecting climate variables requires careful consideration and analysis. For example, heatwaves impacts can’t be estimated using mean temperature alone; instead, maximum temperature or days above 35°*C* and 40°*C* need to be used. Moreover, while some climate variables can impact climate, they are not affected by climate change (e.g. incoming solar radiation) and do not require inclusion in a climate change risk assessment. If solar exposure needs to be assessed, it is more relevant to look at the number of days over 30°*C* rather than solar radiation, as it is more likely to be linked to exposure to the sun.

Some of the above impacts might be not relevant for a specific project location and can be excluded (e.g. sea level rise is not generally applicable for inland locations).

A list of suggested climate variables that can be used as an indicator of the climate change impacts versus climate variables that are not recommended is shown in Table 5:

Table 4 Approach to the selection of climate variables as proxies for extreme weather events.

Change impacts	Poor indicators to use (not recommended)	Good indicators to use
Increase in frequency and severity of heatwaves	• Mean temperature	• Urban Heat Island Effect • Maximum temperature • Number of days over 35°C/40°C /45°C (mean and maximum) • • Number of consecutive days above 35°C/40°C/45°C (mean and maximum)
Increase in frequency and intensity of extreme rainfall and flooding	• Mean annual rainfall	• Maximum rainfall • Number of periods with consecutive rain days over 30mm/day ('heavy-rain periods') • The mean and maximum duration of 'heavy-rain periods' • Monthly distribution of rainfall • Number of days over 50mm/day
Increase in frequency and intensity of storm events	• Annual mean wind speed	• Seasonal wind speed • Maximum wind speed
Storm surges and coastal inundation	• Sea level rise (global mean)	• Sea level rise (local projections) • Storm surge
Increase in frequency and severity of bushfires	• Annual mean FFDI	• Mean seasonal FFDI (fire index) • Maximum FFDI
Landslides	• Mean soil moisture	• Number of days with rainfall over 50mm/day • Maximum rainfall
Drought	• Mean soil moisture • Mean precipitation	• Number of drought periods (no rainfall for over 14 days) • The mean and maximum duration of droughts

Soil cracking	• Mean soil moisture	• Number of days with soil moisture below 10kg/m^2
Solar exposure	• Mean downward solar radiation	• Number of days over 30°C *(mean and maximum)*

3.3.3. Additional data sources

Additional variables such as sea level rise, flooding and urban heat island effect are not available from climate models. The below sections outline data sources that can be used (if applicable).

3.3.3.1. Sea level rise

Sea level rise data are not directly available from CSIRO and NARCliM models. While previous CRA relied on Church et al., 2014 projections, more recent data became available. According to the latest IPCC special report on ocean changes[5], significant sea level rise contributions from Antarctic ice sheet mass loss, which earlier reports did not expect to occur this century, are already being observed. “The sum of glacier and ice sheet contributions is now the dominant source of global mean sea level rise (very high confidence).” [33]

To account for potentially higher sea level rise, we recommend using more recent data available from the Climate Analytics sea level rise tool via http://localslr.climateanalytics.org/. The work leading to the tool has received funding from the International Climate Initiative (IKI) of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety under the project IMPACT implemented by Climate Analytics and its partners Charles & Associates Inc. (Grenada), the Caribbean Community Climate Change Centre, the Secretariat of the Pacific Regional Environment Programme and the Potsdam Institute for Climate Impact Research.

The tool provides local sea-level rise projections based on the Bamber et al. 2019 scenarios[42] and the original Kopp et al. 2014 methodology[43]. The Kopp et al. 2014 methodology was assessed in the IPCC Special Report on the Ocean and Cryosphere as one of the simplified modelling approaches. The contributing components to local sea level rise modelled by Kopp et al. (2014) are[44]:

- Antarctic and Greenland ice sheets based on IPCC AR5 and expert elicitation
- glacier and ice caps based on an improvement of the IPCC AR5 method,
- oceanic processes, including thermal expansion and dynamic effects taken from CMIP5 simulations
- land water storage taking into account changes in population
- all non-climatic contributions combined into background effects

The projections are available for RCP2.6, RCP4.5 and RCP8.5 scenarios. We recommend using the RCP8.5 scenario for the risk assessment. When estimating the impacts of sea level rise, storm tide heights need to be considered. It is assumed that the statistics of storm tides is unchanged in future.

A comparison between old projections (based on Church et al., 2014) and new recommended projections by Climate Analytics are shown in Table 6.

Table 5 Recent sea level rise projection by Climate Analytics vs former projections based on Church et al., 2014. The first value represents the average; the values in brackets are minimum and maximum range.

Data source:	2030	2050	2070	2100	2150	2200
Revised projections by Climate Analytics[43] (90% uncertainty range)	0.16 m (0.8 m - 0.26 m)	0.35 m (0.19 m - 0.62 m)	-	1.15 m (0.6 m - 2.44 m)	1.33 m (0.94 m - 5.51 m)	1.93 m (1.25 m - 8.8 m)
Based on Church et al., 2014 (IPCC 2014) [iii] (90% uncertainty range)	0.14 m (0.10 m - 0.19 m)	0.27 m (0.19 m - 0.36 m)	0.44 m (0.31 m - 0.59 m)	0.66 m (0.45 m - 0.88 m)	-	-

3.3.3.2. Flooding

Flooding can be impacted either by intense rainfall, sea level rise (for coastal areas) or a combination of two. The impact of various sea levels on the coastal areas and flooding can be found using the following online tools:

Table 6 Online sources to assess flooding

CoastAdapt Sea Level Rise and you	The site shows sea level rise and inundation maps for council areas.
Water observations from space	The site provides information about the potential flood areas (in the past). Please, keep in mind that if a site hasn't been flooded in the past, it doesn't mean it won't be flooded in future. The tool also shows the maximum tide height.
Coastal Risk Australia	The site shows changes in coastline based on different sea level projections.
Surging seas Risk Zone Map	The site shows changes in coastline based on different sea level projections.
Marine explorer	A tool provides means to estimate sea level rise allowance (based on Church et al., 2014 projections).

Flood Map	The site shows changes in coastline based on different sea levels.
NSW flood data portal	The site provides flood studies provided for NSW.

When using flood studies, it is crucial to select assessments that include relevant climate change projections for both sea level rise (if coastal) and precipitation. The selected projections must be location-specific and represent RCP8.5. Scenario.

3.3.3.3. Urban Heat Island Effect

Climate change can worsen the urban heat island (UHI) effect and result in even higher air temperatures (Figure 13). Therefore, areas that are already susceptible to UHI and having high heat vulnerability require extra attention. The NSW UNI data is available for SA1 statistical area, 2016, via the SEED portal.

The information about project assets located within those areas needs to be recorded and adapted for. For example, if the site's maximum temperature is predicted to be 45 degrees Celsius, but UHI effect is equal to a 10 degrees Celsius increase, a 55 degree Celsius impact should be considered.

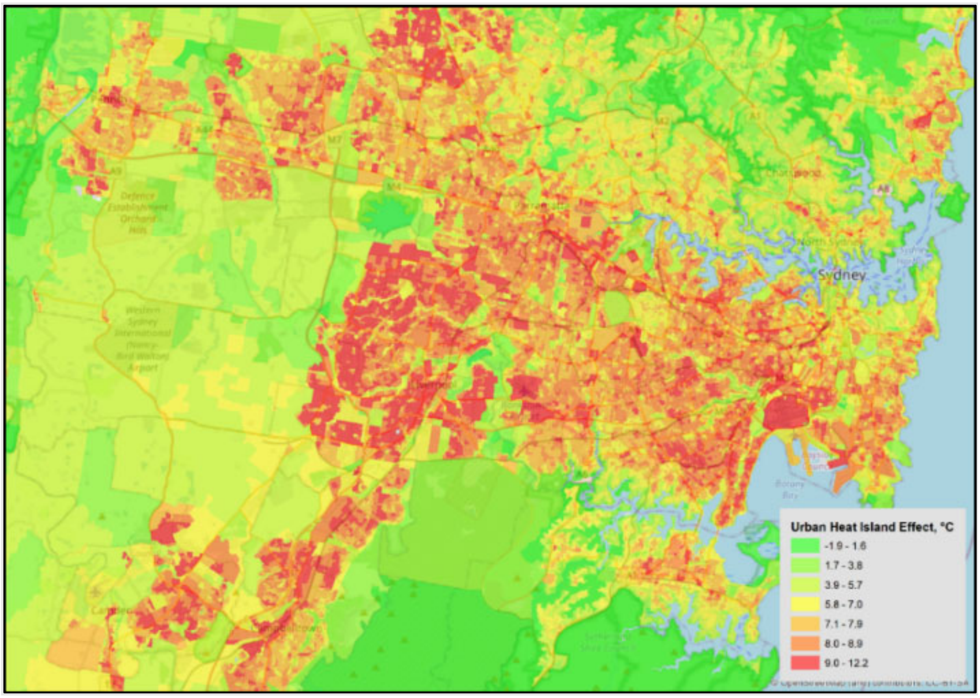

Figure 13 Urban Heat Island Effect for Sydney GMA in 2016 based on SEED data.

3.3.4. Projection scenarios and time series

A Representative Concentration Pathway (RCP) is a greenhouse gas concentration trajectory adopted by the IPCC and used in the IPCC 5th Assessment Report in 2014 (four different scenarios: RCP2.6, RCP4.5, RCP6.0 and RCP8.5). They represent scenarios of different magnitudes of climate change based on assumptions about economic activity, energy sources, population growth and other socio-economic factors. RCP8.5 projections represent a "very high baseline emission scenario" and a mean temperature rise of 4.8°C by 2100.

Rather than working with different IPCC scenarios, it is recommended to work with one chosen scenario. For practical purposes, it is not feasible to analyse multiple scenarios, and uncertainty will be present regardless of how many climate change scenarios are included[46]. Thus, for climate change risk assessment, we recommend using only the RCP8.5 projections. Note that there is no likelihood attached to any of the RCP scenarios, and RCP8.5 is not less likely or unlikely to happen than either of the RCPs. The reason to use RCP8.5 is to ensure that we identify all possible climate risks. This is also an ISCA Tool – Rulings, v2.0 requirement.

When selecting a time series, it is essential to consider the asset's lifespan. A bridge, for example, is likely to have a longer design life than pavement. Establishing these differences will affect the climate projections used and the level of climate risk the asset is exposed to. For example, if a project design life is 100 years, you need to use at least two projection periods (e.g. 2021-2050 and 2071-2100) to understand the future climate impacts across the asset's life. Depending on the project design life, TfNSW accepts there may be justifiable circumstances where only one time series is appropriate. Selection of time series needs to include a 30-year period of data in order to account for climate variability (it is not sufficient to only take one year of data).

Also, it is critical to keep in mind that the selection and comparison of climate projections need to include a consistent selection of baseline period (e.g. it is incorrect to provide climate changes relative to baseline 1990-2009 but compare it to observations for 1970.)

Common mistakes:

- Selected projections from NARCliM (which uses 1990-2009 as a baseline) and compare them to projected changes from CSIRO that uses a different baseline.

- Selected projections from NARCliM (which uses 1990-2009 as a baseline) and compare them to observations at a weather station (located 100 km away) from 1970 to 2010.

3.3.5. Climate projections data analysis (for information only)

CRA's relies on correct selection and analysis of the climate projection data. Incorrect interpretation of future climate can result in underestimating climate change risks and a potential failure of an asset in the future.

Raw gridded data represent numerical matrices with values for each climate variable in each grid node (geographical coordinate). Generally, there is a separate file for each day/hour and climate variable. These data can be loaded into various programming platforms and analysed in any way required. In contrast, the maps (e.g. NARCliM maps) are simply a diagrammatic representation of climate in an area. They can be only used as a reference and visual representation and are not suitable for a detailed analysis. Raw climate data can be downloaded from this portal: NARCliM raw data (registration required).

Our review of the previous CRA has shown a gap in understanding of what type of analysis is required to have meaningful information about climate at project-specific locations. Online climate change tools are designed to provide value in terms of a general overview of Australia's local climate. Those tools are generally not sufficient for conducting a CRA for Transport projects. Both NARCliM and CSIRO online tools have limitations in terms of the depth of the data analysis and are generally not recommended for use as a stand-alone approach. Here are the main limitations of the climate tools and the reason why analysis of the raw climate data is required:

- **Spatial averaging.** CSIRO online tool provides data averaged over sub-clusters covering a large geographical area. This spatially averaged data is not suitable for understanding climate risk at specific geographic locations because of the large spatial climate variability (climate variables in one place can significantly differ from another site that is 20-km away).

- **Inability to use and analyse multiple assets.** Online tools and maps provide excellent means of understanding local climate and future changes in general. However, they are not effective for use on a project with multiple locations because this would require a visual projection of each site on the map making the process inefficient and unreliable.

- **Temporal limitations.** Using online tools is only possible to obtain information about annual mean values, not hourly, daily or seasonal data (in the case of the NARCliM online tool). Due to some climate variables having large temporal variability (e.g. rainfall intensity can change significantly within an hour), using their annual average cannot help identify weather extremes required to estimate climate risks.

- **Inability to select maximum values.** We must account for the highest level of risks and consider the top range of projected climate values. However, the online tools and maps provide an average of climate models, and their application for CRA may lead to underestimating future risks.

- **Limited parameters and thresholds.** Various questions may need to be answered for each project, which requires flexibility in the way we analyse climate variables, which is generally not possible via online tools (because the number of parameters is fixed) (e.g. a number of days over 45 degrees is available, which doesn't allow us to know the number of days over 50 degrees).

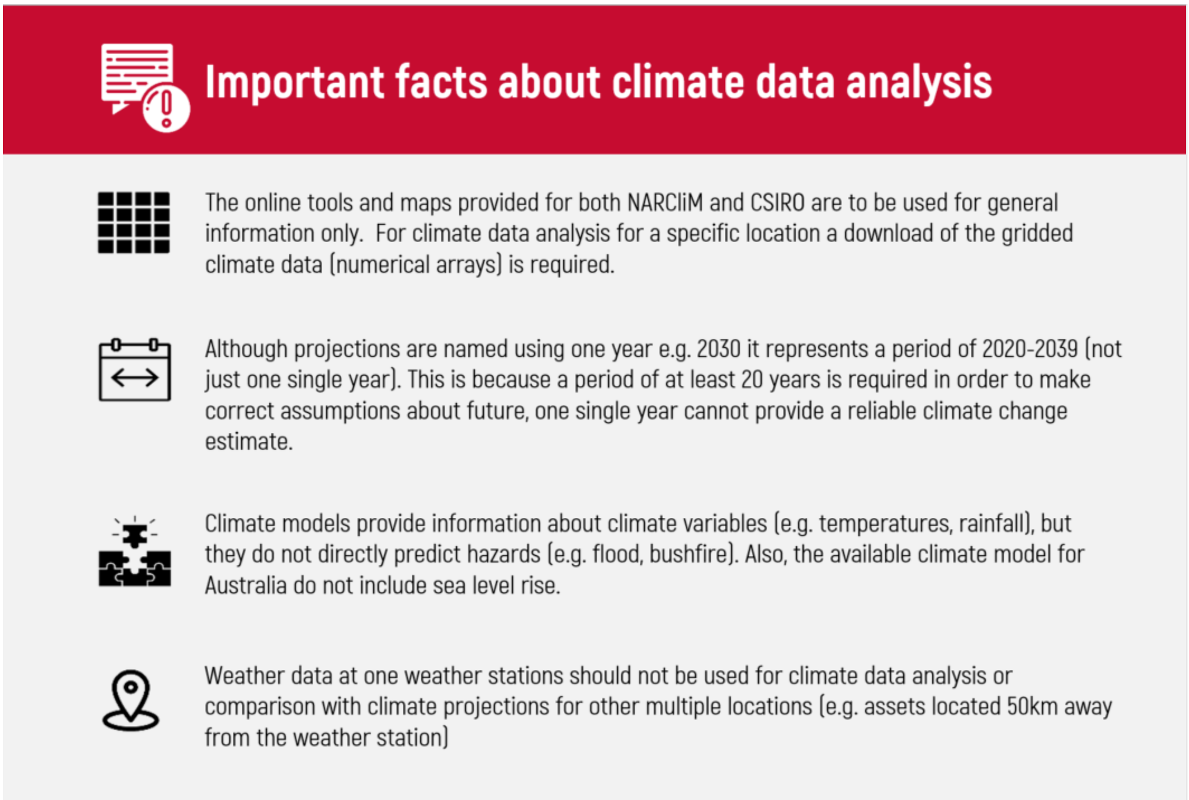

Figure 14 Important facts about climate data analysis

3.3.6. TfNSW Climate Risk Assessment Tool 1

As shown in the previous section, analysis of the raw climate data is an essential part of any CRA. To make this process time-efficient and more effective a 'TfNSW CRA tool 1: Climate data' (CRA Tool 1) has been developed (available from TfNSW on request).

The tool includes two components:

- A model built using Matlab software. It uses raw climate data together with parametrisation and optimisation algorithms to assess multiple climate change projections for any selected geographical location. The model produces a database with climate projections for various sites.
- A user-friendly excel tool that uses the database (output from Matlab model) and shows climate projections customised specifically for CRA.

The model that feeds that data in the tool combines 6 raw climate projection data ensembles from NARCliM. It selects the higher range of values (90th percentile of data) out of all projections for each unique geographical location, thus creating a new data set that is more suitable for climate change risk assessment. Keep in mind that this data is not representative of the exact climate in future but is built for risk estimation purposes only. The tool simplifies the process of linking climate projections to risks by providing an appropriate selection of climate indicators (e.g. instead of looking at mean annual precipitation, the tool provides the number of days with rainfall of 25mm/h, duration of drought periods and others).

In addition to climate model data, the tool includes the latest Sea Level Rise projections (from Climate Analytics) and identifies whether a location sits near the coastline. It also provides data for Urban Heat Island Effect (only the data about the current state are included due to the data availability) and various resilience indicators such as heat vulnerability index and disaster resilience. Appendix 1 provides a list of all available parameters (climate indicators) that the tool offers. More details on how to use the tool and the model technical background can be found in the Tool Manual.

TfNSW CRA tool 1 also provides two types of CRA pre-screening: General pre-screening (per location) and detailed pre-screening (per location and asset type).

3.3.7. General CRA Pre-Screening

After the data analysis is completed, a general pre-screening can be conducted to estimate the overall number of climate risks per project location and prioritise options.

The general pre-screening in the CRA tool is linked to climate projections and provides ‘yes’/’no’ depending on the exceedance of a set threshold. Thresholds for all included parameters are provided in the tool or can be found in the Tool Manual.

It is important to always refer to climate change projections specific to a location when conducting a CRA pre-screening. A consultation with relevant stakeholders is required to understand whether the change in the climate variable is relevant to the project location.

General CRA Pre-screening is a critical step in the CRA process and needs to be linked to the detailed pre-screening and complete CRA rather than being treated as a stand-alone exercise. It enables a more time-efficient run of detailed pre-screening as all relevant climate variables and project locations are pre-selected during general pre-screening.

3.4. Step 4: Detailed Pre-Screening

Detailed CRA pre-screening (as per TfNSW CRA Tool 1) is linked to climate projections per location and requires selecting all relevant disciplines and corresponding asset types that changes in climate variables may impact. If possible, this process needs to be conducted in consultation with relevant designers (or other experts) representing each discipline.

Similar to the general pre-screening, detailed pre-screening has to be linked to a complete CRA: all assets at risks selected during detailed-pre-screening need to be included in the risk register (providing risk statements per asset) or CRA Tool 2. This ensures consistency and efficiency of the overall process, and also enables integration of the risk statements to Risk Management and Asset Management registers.

3.5. Step 5: Preliminary risk table (including risk statements)

Once relevant climate variables have been identified, associated climate risks will need to be identified for the project. When developing climate risk statements, all relevant climate change variables and their associated project impacts need to be considered. At least a preliminary CRA table needs to be developed prior to any CRA workshop or stakeholder engagement. Having access to pre-determined information can improve efficiency and help potential stakeholders efficiently refine and confirm risk settings.

A preliminary CRA table should include the following:

- Risk statements
- Risk type (direct/indirect)
- Corresponding asset type and subtype
- Design life
- Corresponding climate variable
- Climate projections for the relevant period
- Applicable project locations
- Preliminary identification of risk level
- Preliminary adaptation measures

3.5.1. TfNSW Climate Risk Assessment Tool 2

To assist with developing risk statements and conducting a compete CRA, the 'TfNSW CRA Tool 2: Risk Level' (CRA Tool 2) can be used (technical specifications of the tool can be found in the Tool Manual).

The tool has been developed in consultation with Transport Risk Management, Asset Management and project teams, and it is consistent with TERM and consequence/likelihood criteria (Appendix 5). The tool is linked to a climate risks database that gets regularly updated (including automated learning algorithm that records any new risk statements identified). It enables a user to automatically load risk statements for a selected asset (information about relevant assets can be extracted from the Detailed Pre-Screening tool), relevant risk type, climate variable and location-specific climate projections. The tool provides an option for estimation of inherent risk levels, adaptation measures and residual risks and provides an overall summary of the identified risks (more information can be found in Section 5.2).

3.5.2. Construction of preliminary risk statements

To ensure all risks are considered across the project lifecycle, it will be critical that the climate risks are incorporated into the broader project risk register. For this reason, it is recommended that risk statements are linked to asset types. An example of a preliminary risk table is shown in Table 8.

Table 7 Risk Register Example

Discipline	Asset type	Design Life, years	Climate Variable Type	Climate Variable	Projections 2020-2039	Projections 2060-2079	Risk type (Direct/ Indirect)	Risk statement
Construction /Maintenance	Equipment	10	**Heat-related**	Heatwaves, more days over 40°C	+4 days from 4 days	+6 days from 2 days	**Direct**	More days over 40°C resulting in top work for welding track
Electrical	Electrical Substation Equipment	40	**Precipitation-related**	Hail	n/a	+30%	**Indirect**	More frequent hail events resulting in damage to utility substation equipment
Electrical	Electrical Substation Equipment	20	**Precipitation-related**	Maximum days with rainfall intensity >25mm/h	+2 days from 8 days	+4 days from 8 days	**Direct**	Increase of the number of heavy rainfall days resulting in higher humidity leading to degradation of switchboard comp-s

Additional risks statements can be selected based on a combination of data from previous climate change risk assessments and in consultation with relevant stakeholders. It's essential to keep in mind that this step should only include only risk statement collection. **Risk level should not be copied from previous CRAs as it has to be unique for each project, and its determination requires data analysis.** In other words, a risk level being low for one location does not guarantee the level of the same risk being low for a different location.

When adding new risk statements to the register, it is recommended to keep them concise and use the "Risk -> Impact", e.g. "Decreased performance of signalling equipment over time, leading to failure ahead of design life". Nevertheless, the information needs to be meaningful, and we recommend avoiding general or vague statements such as: "Project delays". Instead, it's better to say: "Stop work for construction site leading to project delays and financial implications".

Also, it is better to provide a climate variable link in a different column than describes it in the risk statement to avoid overly long risk statements. The climate variables should be defined using thresholds rather than overall changes in a climate variable, e.g. "number of days with rainfall exceeding 200mm" is preferred over "increase of rainfall events". This approach can provide more clarity to the designers and improve the risk evaluation's reliability.

3.5.3. Identification of preliminary adaptation measures

Once preliminary risk statements have been identified, a list of preliminary adaptation measures (risk mitigation measures) can be constructed. This will ensure that a broader list of adaptation pathways is available to CRA stakeholders.

It is essential to include a range of adaptation options that cover different adaptation types for consideration. There are two ways to identify adaptation types. The first define types of adaptation measures that can reduce risk by addressing one or more of the three risk factors: vulnerability, exposure and hazard (Figure 15)[5]. The second approach aims to divide adaptation measure based on the type of intervention, namely hard, soft and ecosystem-based adaptation (Figure 16).

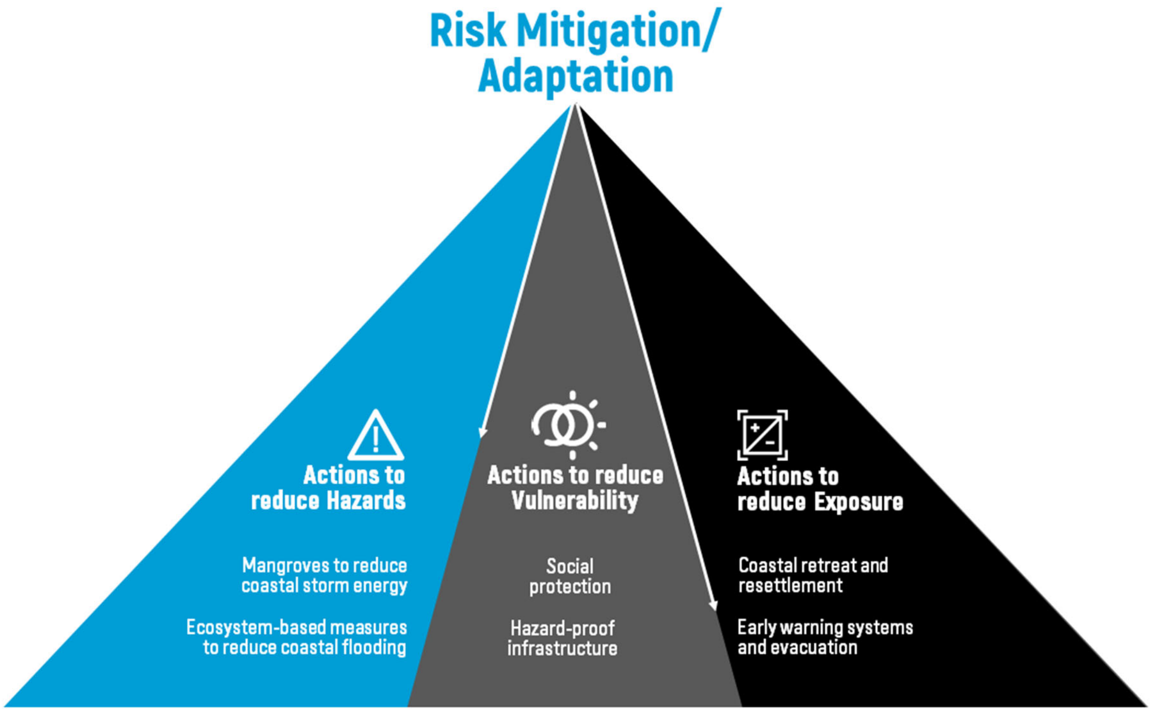

Figure 15 Three types of adaptation (risk mitigation) measures

In some instances, ecosystem-based solutions can significantly reduce the likelihood of high or very high risk. They can also provide a more cost-effective approach. Ecosystem-based solutions can address multiple threats at once - help mitigate the urban heat island effect and contribute to climate change mitigation and air quality. You can find an extensive review of nature-based adaptation measures using the Landslide Risk Mitigation Toolbox (LaRiMit).

It will be essential to engage with the project's detailed designers and TfNSW project manager to discuss and recommend substantive design changes resulting from the CRA.

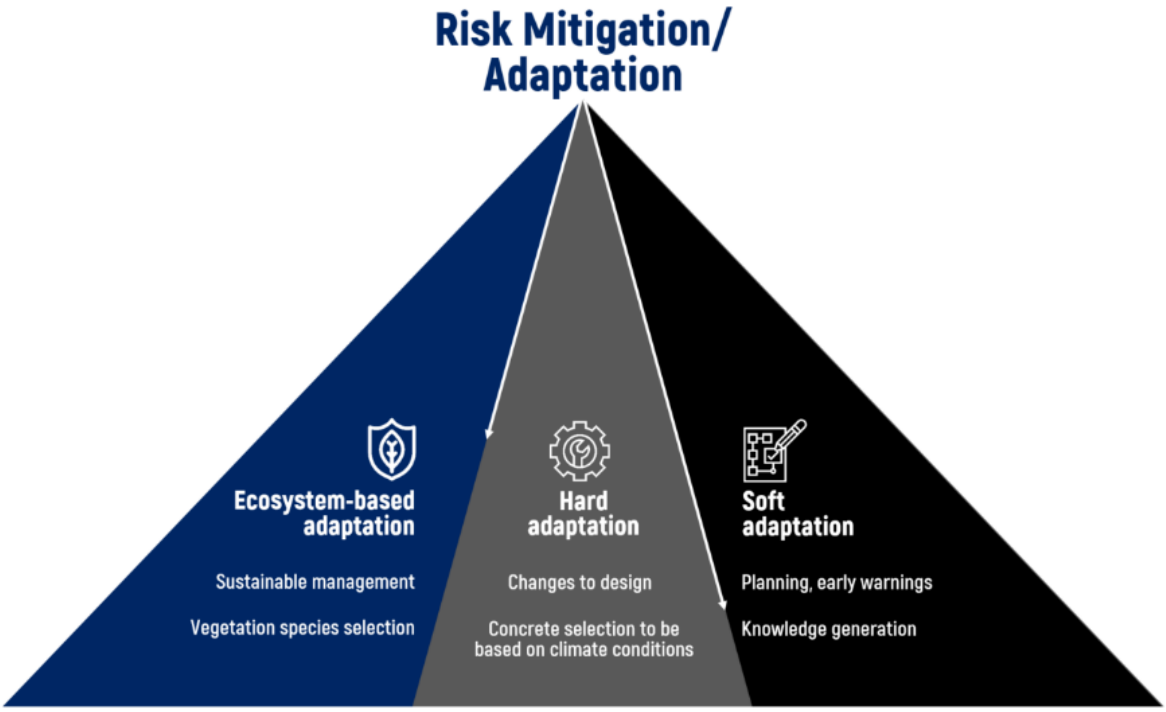

Figure 16 Three types of adaptation (risk mitigation) measures

3.6. Step 6: Assessment team selection

In line with good practice climate risk assessment, analysis of preliminary risk register and risk ratings should be developed in consultation with key members of the project team. Collaboration with key stakeholders better enables a comprehensive assessment of key project risks associated with climate change. TfNSW recommends the following representatives to participate in the development of the CRA:

Table 8 Recommended CRA stakeholders/ participants.

TfNSW:

Sustainability Manager
Project Sustainability Officer
Project Design Manager
Project Engineer
Technical Manager
Asset management team representative
Discipline leads (where available and part of the project team):
Architecture & Services (including urban design and landscaping)
Civil & Structures (including Stormwater)
Construction/Maintenance
Drainage
Electrical
Environment
Mechanical
OHW
Operations
People
Property
Signalling & Control Systems
Technology & Telecommunications Systems
Track

4. Complete CRA

4.1. Step 7: Undertake complete CRA

During the CRA process, preliminary risk statements need to be assessed by stakeholders, and any new suggested relevant risk statements need to be added to the risk register. Each risk statement has to be linked to an asset, climate variable and specific location. It is recommended to use TfNSW CRA Tool 2 to construct the risk register to ensure consistency across all Transport projects. The selection of relevant risk statements should be made in consultation with relevant project stakeholders.

4.1.1. Stakeholder recommendations

Climate risks should be assessed in collaboration with key stakeholders. This can be done via a 1-1 approach, in workshop environment, or similar. The following checklist can be used to assist the process

Table 9 CRA checklist.

Milestone	Due date	Completed
Climate Data and Project Assets		
Data about each relevant climate variable are obtained for each project location either from the 'TfNSW CRA tool 1' or using an independent data analysis (for near and far future).		☐
Thresholds for each climate variable are defined, and climate risk statements are provided for each climate impact type.		☐
List of past climate impacts and current exposure to extreme weather events		☐
Key project components relevant to the project, design life		☐
General CRA pre-screening highlighting the number of climate risks (relevant climate variables) per location		☐
Detailed CRA pre-screening showing all assets at risks for each of the project locations		☐
The TfNSW CRA Tool 2 is prepopulated with all relevant preliminary risk statements linked to selected assets and climate variables (optionally preliminary adaptation measures added).		☐
Scope and Engagement		
Clear identification of the project boundary and scope of works		☐
Relevant experts and stakeholders are identified, their availability for 1-1 evaluation or workshops confirmed		☐
The preliminary risk table provided to stakeholders prior to discussion		☐

4.1.2. Identify risk levels

Once a project's climate risk statements have been identified, their corresponding risk ratings will need to be allocated. Risk is generally defined as the effect of uncertainty on objectives (ISO, 2009). In the context of risk assessment, vulnerability is linked to sensitivity and exposure to climate risks. In a risk-based approach, the risk level can be estimated using likelihood and consequence. It is recommended to use Table 11 (Transport Enterprise Risk Management) to ensure alignment with the project's broader risk assessment process.

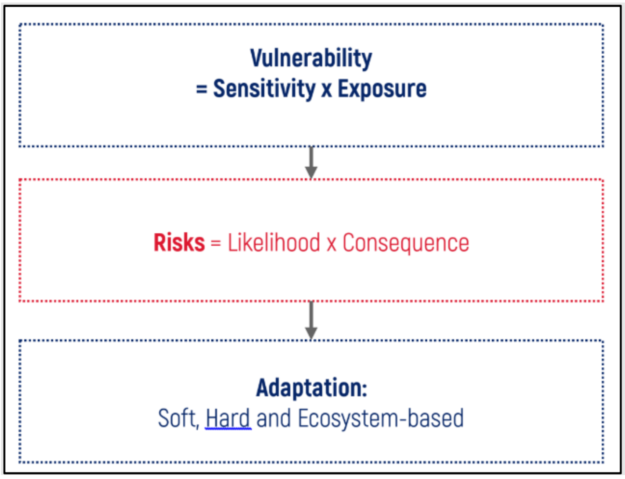

Figure 17Climate change risk assessment parameters

Risk assessments rely on the allocation of both consequence and likelihood ratings to determine the overall risk level. It is essential to keep in mind that in this context, we're estimating the likelihood of the consequence associated with the risk (impact) – not the likelihood of the risk itself or the "likelihood of climate change". The likelihood of this context is the probability of the identified consequences.

Assessing the risk's consequence explores the magnitude of impact taken the risk (hazard) takes place. For example, if train stations, tracks or signalling equipment were to be impacted by a flood, what would the consequence of this impact be? TfNSW recommend looking at the correlation between the past effects and the magnitude of implications to estimate potential consequence areas for severe weather events (e.g. rainfall resulted in station flooding, financial impact, number of injuries).

Table 10 Transport Enterprise Risk Management (TERM) risk table

Risk Matrix Evaluation Table

Risk Ratings			Consequence					
A – Very High B – High C – Medium D - Low			Insignificant	Minor	Mode	Major	Severe	Catastrophic
			C6	C5	C4	C3	C2	C1
Likelihood	Almost certain	L1	C	B	B	A	A	A
	Very likely	L2	C	C	B	B	A	A
	Likely	L3	D	C	C	B	B	A
	Unlikely	L4	D	D	C	C	B	B
	Very unlikely	L5	D	D	D	C	C	B
	Almost unprecedented	L6	D	D	D	D	C	C

Previous climate risk assessments solely relied on the 'workshop discussion' approach to identify risk levels; however, due to the lack of consistent methodology, the process has been somewhat unreliable and subjective. The problem has been pointed out by Sydney Trains report[41] stating that "our perception of risks is inaccurate and inadequate". Therefore, it is recommended to use the TfNSW CRA Tool 2 to identify consequence and likelihood levels less subjectively.

To assess the consequence level of an event, you need to work from the point of view that the risk has already occurred (TERM). A tool user can select relevant consequence areas and identify the consequence level for each risk statement, after which a total weighted consequence level is calculated.

Two factors are considered when evaluating the likelihood: historical frequency of the given impact/consequence and future frequency (where the estimation must rely on climate change projections for the specific location). Once the likelihood and consequence ratings have been identified, the project's climate risks are determined based on the risk matrix (Table 11).

All risks should be assessed for the corresponding time series, and ratings should include the consequence and likelihood criteria assigned to the associated risk rating. It has to be clear why a particular consequence and likelihood levels have been allocated; it is not acceptable to give all risks 'low' and 'medium' rating without justification. The TfNSW CRA Tool 2 includes sets of questions designed to help identify risk levels, and all responses provided during the tool usage are recorded in the background, thus providing evidence of why a certain risk level was selected.

This task has to be done as part of a collaborative approach with key internal and external stakeholders. CRA facilitators should not simply copy risk levels from previous assessments as they need to be unique to each location.

4.1.3. Risk owners

One of CRA's critical parts is the assignment of risk owners to each identified risk. It ensures that someone in the organisation is accountable for the risk. When using 'TfNSW CRA Tool 2' you can add a risk owner for each risk statement, and it is highly recommended to do so once risk statements are identified.

It is not recommended for risk ownership to be assigned to a body, such as a business unit or committee. A specific position needs to be provided to remove any doubt about who is responsible for managing the risk (according to TERM). The risk owner for each risk should be a person who has the most influence over its outcome. ISO 27000:2014 defines the risk owner as a "person or entity with the accountability and authority to manage a risk." Asset owners can be assigned as risk owners if they have enough authority to resolve potential risks.

It is essential to keep in mind that risk managers are not risk owners, and they are only responsible for maintaining risk registers. Risk owners are different for different phases of the project, and there is a person responsible for the transfer of the risk register between the project phases. Figure 18 provides information about risk owners for each of the project phases. Individual risks on the risks register are the responsibility of individual senior project managers in charge of the asset that the risk relates to (e.g. Senior Project Manager for Social Sustainability is the owner of the social risks).

At the design phase, the ultimate risk owner is 'Director Project Development' or equivalent, while Individual Senior Project Managers responsible for the development of an asset are accountable for each corresponding risk. The ultimate risk owner is Transport for NSW Authorised Engineering Organisation (AEO) and Project Director or equivalent during the delivery phase. Individual Senior Project Managers responsible for delivering an asset are accountable for each corresponding risk. During the operation Director Services or Service delivery or equivalent owns the risks. The transfer of risks between design and operation phases occurs as part of the project handover, and the Interface Manager is responsible for the transfer. A person leading the Operational Integration team, e.g. Director of Business and Operational Integration or equivalent, facilitates the transfer of risks between delivery and operation.

Overall, the decision on who is responsible for the risk should be based on identifying who has the most capability and influence over the risk area. This can be supported by a consequence matrix specific to each asset. This list is provided in CRA Tool 2 and can be used as a guide to identifying risk control owner and task owner (e.g. if the risk should go to the Safety team because the risk consequence is the highest for that area). The link to the asset can assist in identifying whether the risk should go to the design team or technical specialists, for example (Figure 18).

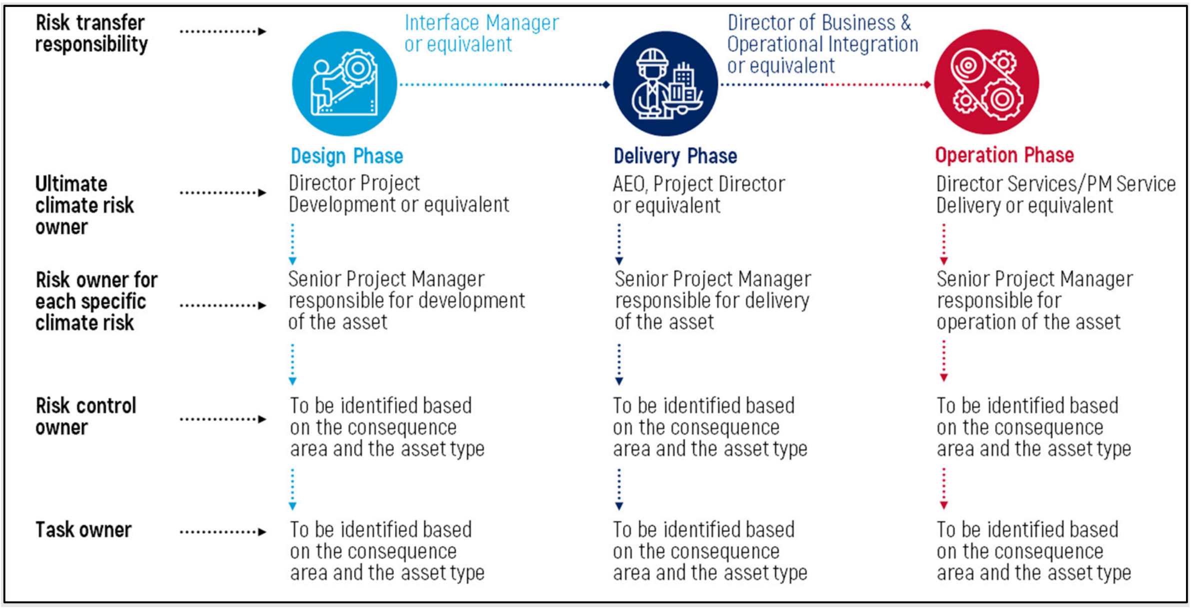

Figure 18 Climate Risk owners for each project phase.

Risk owners are responsible for (per TERM):

- Ensure that the risks they own are managed appropriately
- Complete relevant risk reporting
- Ensure that the risk review process is carried out in a timely fashion
- Ensure the currency of risk registers and respond to any assigned actions
- Ensure adaptation measures are assigned
- Monitoring progress

4.2. Step 8: Selection of adaptation measures

This step involves identifying risk treatments (adaptation measures/controls) and developing an adaptation plan. Controls are defined as a measure that reduces risks by reducing the likelihood of the risk occurring or/and reducing the consequence (TERM).

Adaptation actions must be identified for all risks rated ‘high’, ‘very high’ (to meet Level 1 ISCA v1.2. Cli-2 requirements) and a defined proportion of ‘Medium’ risks (25-50% to complete Level 2 and over 50% to meet Level 3 ISCA v1.2. Cli-2 requirements) in a way that reduces the risk level (unless otherwise indicated by TfNSW). Adaptation measures either reduce the likelihood or consequence of an impact (or both), thus reducing the corresponding risk level. It is important to keep in mind that adaptation measures are meant to reduce the risk level – not to eliminate it. It is likely to have remaining residual risks even after adaptation.

The selected adaptation measures should comprise actual or proposed adaptation initiatives rather than aspirational, potential actions. TfNSW should feel confident that the associated climate risk will be reduced as the identified adaptation actions will be integrated into the design. TfNSW reserves the right to request evidence of how adaptation actions have been incorporated into the project. A complete list of adaptation options must be provided for each risk, even if not all of the adaptation actions are currently feasible or desirable.

When assessing whether current practices and standards are sufficient to mitigate climate change risks, CRA stakeholders and participants must understand that the future impacts of climate change are likely to go beyond their experience and the adaptation standards that historically have been applied may not work in future. “There is a tendency to want to say “apply leading current practice everywhere” – this is fine as one option, but its limitations in the face of climate change should be firmly addressed”[26]. The current standards and practices are not the same as adaptation measures and they can be used but only in an altered way (e.g. expanded in scope)[47].

Factors to address when selecting adaptation pathways:

1. Do any options have use-by dates (e.g. planting drought-tolerant species that are not adaptable to the longer-term, more dry conditions)
2. Are there any cross dependencies and whether an adaptation option will reduce one risk but will increase another risk (e.g. removing trees as an adaptation option for high wind speed can result in increased run-off and increase of the flood risks and erosion)
3. Ensure that the adaptation options do not exacerbate the urban heat island effect (if high)
4. Consider any other reasons for not implementing the option (e.g. if it's maladaptive or results in poor life-cycle outcomes)
5. When the implementation of the option needs to take place
6. How the option can be initiated
7. Who is responsible for implementing the option

Prioritising of adaptation measure should be based on the following criteria:

- **Mutually beneficial**: reflects worthwhile actions that deliver a net socio-economic benefit regardless of the level of climate impact. These types of measures include those justified under current climate conditions (including those addressing its variability and extremes) and are further explained when their introduction is consistent with managing risks associated with projected climate changes.
- **Cost-Effective**: actions for which the associated costs are relatively low and for which future benefits are comparatively large.
- **Co-benefit**: actions that will contribute to the minimisation of climate risk and deliver other social, environmental, or economic benefits for the project.
- **Flexible or Adaptive Management**: rather than undertaking large-scale adaptation in one fell swoop, adaptive management involves introducing incremental adaptation options. This approach reduces the risks associated with uncertainty since it allows for gradual adaptation. Measures are presented by assessing what makes sense today but designed to allow for incremental change (including changing tack) as knowledge, experience, and technology evolve.

At the end of the adaptation measures assessment an adaptation plan needs to be developed highlighting the selected adaptation measures. In addition an implementation plan needs to be completed covering specific tasks, responsibilities and time planning (according to ISO 14091: 2021).

4.3. Step 9: Reassess risks (Residual risks)

Once the assessment team has identified relevant adaptation actions for all 'very high', 'high' risks and a selected percentage of 'medium risks', the risk assessment process should be re-run to estimate the revised level of risk associated with the project (residual risk). This canbe done in consultation with relevant experts and by applying TfNSW Tool 2 to identify if proposed adaptation measures reduce consequence or likelihood levels. Where two different time series have been assessed for the project (e.g. 2030 and 2070), the identified adaptation measures should ensure the risk rating is reduced across both time series.

A clear description of how proposed adaptation measures can reduce the risk level should be provided in the risk register for all 'medium' to 'very high' risks. If adaptation measures are out of project scope, it should be mentioned in the risk register. It is essential to keep in mind the risks need to be acknowledged within the risk register regardless of the project's ability to eliminate them.

A priority should be given to adaptation measures that are more effective in reducing the risk level. The assessment should also include considerations on how identified adaptation measures will be considered in the design report /drawings.

As part of this step, a summary demonstrating a total number of all inherent and residual risks (by corresponding risk level) and key climate variables linked to the risks should be provided (available in the 'TfNSW CRA Tool 2').

At the end of the assessment and adaptation, there should be no 'high' and 'very high' risks remaining, as this would indicate a breach of contract requirements. However, if it's not possible to reduce risk levels, residual high or very high risks should be documented in the Asset Risk Register and transferred to the asset owner in the commissioning stage. The Director of Business and Operational Integration (or equivalent) responsible for the transition from the project delivery to operation should be made aware of the residual high and very high risks.

5. Post-CRA

5.1. Step 10: Report, monitor and review

5.1.1. Report

After completing the detailed design, a summary report must be provided to TfNSW. Table 12 provides an at-a-glance summary of the report inclusions Transport for NSW (TfNSW) requires as part of a Climate Risk Assessment report submission. A completed risk register also needs to be submitted (preferably as a populated TfNSW CRA Tool 2). All information captured in the risk register needs to be complete, accurate and up to date (TERM).

Results of adaptation planning need to be communicated to project designers and inform the implementation steps.

Table 11 CRA report inclusions

Report Components	Included [□]
Climate Data and Project Assets	
A list of any relevant recent and historical weather events that have impacted the project site or surrounding areas	
A list of relevant climate variables including appropriate data sources for at least two different time periods. Climate projections to be location-specific and include consistent baselines, data analysis methods/tools used, and raw data sources. Note: Depending on the project design life, TfNSW accepts there may be justifiable circumstances where only one time series is appropriate.	
Tabulated breakdown of major project components and associated design life	
Scope and Engagement	
Clear identification of the project boundary and scope of works relevant to risk assessment (what type of adaptation measures would be in or out of scope)	
List of stakeholders consulted in the development of the risk statements (as a minimum described in Section 5.6)	
Risk Assessment Approach and Assessment	
A statement summarising which risk assessment parameters have been applied (e.g. TfNSW Enterprise Risk Management (TERM) assessment criteria together with TfNSW CRA Tool 2)	
Summary of the total number of climate risks identified for the project, including a breakdown of 'very high', 'high', 'medium' and 'low' risks	
Discussion regarding the risk tolerance and level of acceptability to be provided for all 'high' and 'very high' and selected percentage of 'medium' risks	
A copy of the project's climate risk (risk statements, risk levels, adaptation measures) to be included in the report as well as provided as a populated TfNSW CRA Tool 2 or an Excel spreadsheet in the same format. Risk statements must be linked to a specific asset type, climate variable and location.	
Adaptation and residual risk	

Summarise the adaptation actions identified for all 'medium' to 'very high' risks. Inclusion of adaptation actions within the risk assessment table to be included in the report	
The effectiveness of adaptation measures in reducing risk level is described for each adaptation measure and justification for inclusion/non-inclusion in the design report. A detailed outline of how the adaptation actions will be included in the design report and reference drawings	
Inclusion of residual risk rating with the risk assessment table	

5.1.2. Monitor

Monitoring is an essential element of the process and involves checking the effectiveness of risk treatments and the inclusion of any new data and climate projections when they become available. This step is critical for continuous improvement and effectiveness of risk management.

We recommend for projects to develop a monitoring plan that includes a list of the people involved:

- persons responsible for data and information collection
- person responsible for analysis of the results of monitoring
- persons reporting the risks
- persons responsible for the risks.

The plan should also include trigger points that (if reached) indicate that new action or set of actions is required.[48]

Three lines of defence for responsibilities in review and monitoring climate risks include risk owners, risk managers and internal audit function.

5.1.3. Review

This guideline focuses on supporting a consistent approach to how climate risk assessments should be undertaken and offers a baseline from which to progress and advance how climate risk and resilience is considered on a project. This process requires ongoing improvement as the research on climate risks, and resilience is continuously growing and evolving.

The approach and the risk register need to be continuously reviewed and updated. All risks must be considered in the context of tolerance and acceptability. Table 13 outlines how often certain risks should be reviewed.

Table 12 TfNSW Risk Tolerance and response table (TERM).

Risk rating	Response	Review Frequency
Very High "A"	**Very High** risks are generally intolerable and should be avoided except in extraordinary circumstances. An alternative solution must be found, and all necessary steps must be taken to reduce the risk below this level without delay.	Monthly update of risk register by the risk owner
High "B"	**High** risks are undesirable. They can only be tolerated if it is not reasonably practicable to reduce the risk further. High risks are considered to be on the verge of being unacceptable and must be given immediate priority.	Monthly update of risk register by the risk owner
Medium "C"	**Medium** risks are generally tolerable if it is not reasonably practicable to reduce the risk further. Additional treatment measures should be sought if significant benefit can be demonstrated and/or there is an additional treatment measure which is recognised as good practice in other like environments.	Two monthly updates of risk register by the risk owner
Low "D"	**Low** risks are considered to be broadly acceptable. If options for further risk reduction exist and costs are proportionate to the benefit, then implementation of such measure should be considered.	Quarterly update of risk register by the risk owner

While not an absolute requirement, those wishing to adopt a more holistic approach to climate risk are encouraged to think beyond completing a CRA and consider climate risk more broadly in relation to resilience, vulnerability, and interdependencies. The analysis of risk interdependence explores an expanded remit of climate impacts to consider the knock-on effects borne out of a particular event. For example, a power outage resulting from a heatwave event may affect train signalling, which may affect passenger services, which may have an economic impact resulting from stranded commuters being unable to get to work. This approach requires an enhanced level of stakeholder engagement and consultation to enable the consideration of risks arising from interdependencies between the project asset and the assets and services provided by other stakeholders.

5.2. Integrating climate change into asset management plan (AMP)

The Transport AMP demonstrates alignment with the Strategic Asset Management Plan (SAMP) and its objectives. Service providers should submit AMPs to TfNSW each year via the relevant TfNSW contract managers, as appropriate. The TfNSW Asset Management Framework includes consideration of assets' resilience to incremental weather changes.

Including climate change risks into asset management plans provides an opportunity to incorporate climate risk mitigation strategies into the short- and long-range budgets, address the risks associated with current and future extreme weather events and climate change, and minimise the associated impacts focus on improving system resilience. It can also help establish an approach to monitor all identified high risks. Therefore, this step aims to establish a strong relationship between asset management and climate change impacts.

A critical aspect of aligning CRA to Asset Management is ensuring that all recorded risks statements are linked to a particular asset and that all asset categories are aligned to Transport Asset Classification Standards. This can help to ensure that findings of the CRA can be implemented into the design of each asset. Climate change risk consideration can be included in the asset management plan at each plan section[49]:

Table 13 Potential for the inclusion of climate risk considerations at different Asset Management Plan sections

AMP section	Potential climate risk considerations
Introduction	• Describe expected trends on how extreme weather events might change in the future and how they can impact assets.
Asset Management Objectives – Operate / Maintain Stage	• Identify which objectives are most susceptible to extreme weather-related risks—consideration to reduce extreme weather risks in achieving these objectives. • Consider performance measures related to asset risks and potential damage due to extreme weather events. • Identity which performance measures will be most affected by the influence of extreme weather (Performance Assessment). Evaluate how these performance measures linked to other AMP sections and how they may cause an exacerbated impact on the AMP's success.
Customer and service outcomes	• Link to the AMP objectives • Climate change impacts on customers can be considered in this section.
Asset portfolio	• Evaluate frequency, type of extreme weather, and impact of the event by asset type—estimate typical replacement costs such as labour, equipment, and materials for different asset types. • Include a list of possible future impacts on assets due to shocks and stresses related to climate change. • Identify if certain types of assets more vulnerable to extreme weather events than others
Asset management framework	• Lifecycle management: how maintenance programs can be adjusted to account for extreme weather considerations • Asset rehabilitation or reconstruction design to consider extreme weather and climate change • Capture climate change risks in the risk register

AMP section	Potential climate risk considerations
Current Asset Performance and Condition	• How assets have been affected by extreme weather-related events • Future changes in extreme events • Frequency of weather-related incidents (current and future) • Weather-related delays • Tolerance of facilities or assets to climate change risks
Summary of Balancing Cost, Risk and Performance	• How extreme weather-related impacts are considered in the lifecycle management of the assets • Risk of recurring damage (due to extreme weather events) and the cost of future repair • Describe how risk-based asset inspections and monitoring take into account potential extreme weather impacts • Describe how extreme weather-related risks taken into account in maintenance planning • Emergency response plans for extreme weather events • Monitoring and reporting processes for climate risks
Options/Opportunities (funding options)	• Funds spent in responding to extreme weather events • Identify which assets have had the greatest amount of funding allocated to reconstruction for recovery from extreme weather events • Funds allocation to extreme weather risk monitoring/mitigation • Short- and long-term financial needs associated with climate change risks. Budget allocation. • Describe strategies for mitigating the potential impact of extreme weather events considered as part of the investment strategies

6. Related documents and references

Related documents and references

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Appendix 1: TfNSW CRA Tool 1 Parameters

Table A1. CRA Tool 1 variables

Type	Climate indicator	Source	Description	Time period
Social	Heat Vulnerability Index (current state)	SEED+ CRA Model	Identifies NSW areas where people are more vulnerable to the urban heat impacts based on exposure, sensitivity and adaptive capacity. The index ranges from 1 to 5, where '0' represents low exposure, low sensitivity and high adaptive capacity, whereas '5' means high exposure, high sensitivity and low adaptive capacity. Due to the data limitation, only the current state's value is provided (no future projections available).	Current state only
Social	Disaster Resilience Index (current state)	+ CRA Model	It is an overall measure of disaster resilience formed from coping and adaptive capacity. Disaster resilience is the capacity for communities to prepare for, absorb and recover from natural hazard events and to learn, adapt and transform in the face of future events. The following values correspond to Disaster Resilience: Low is 0-0.3, Moderate is 0.4-0.6, High is 0.7-1. Due to the data limitation, only the current state's value is provided (no future projections available).	Current state only
Heat-related	Maximum daily temperature including Urban Heat Island, °C (current state)		The daily maximum temperature (90th percentile of 30-year data). Urban areas become significantly warmer than surrounding areas when there are less green cover and more hard surfaces which absorb, store and radiate heat. The UHI value shows air temperature increase additional to the climate projections. Due to the data limitation, only the value for the current state is provided (no future projections available). For the historical data we assume UHI to be one degree lower.	1961-1990 (baseline), 2021-2050, 2051-2080, 2071-2100
Heat-related	Minimum temperature, °C	NARCliM 1.5 + CRA Model	The minimum temperature recorded over 30 years	1961-1990 (baseline), 2021-2050, 2051-2080, 2071-2100
Heat-related	Number of days over 35°C	NARCliM 1.5 + CRA Model	Number of days per year with temperatures higher than 35°C (90th percentile of 30-year data).	1961-1990 (baseline),

Type	Climate indicator	Source	Description	Time period
				2021-2050, 2051-2080, 2071-2100
Heat-related	Number of days over 40°C	NARCliM 1.5 + CRA Model	Number of days per year with temperatures higher than 40°C (90th percentile of 30-year data).	1961-1990 (baseline), 2021-2050, 2051-2080, 2071-2100
Heat-related	Average Humidity at temperatures over 40°C	NARCliM 1.5 + CRA Model	High humidity combined with extreme temperatures can have significant impacts on health of customers and staff. Considering humidity when discussing temperature increase is critical to understand how the increase would "fee llike"	1961-1990 (baseline), 2021-2050, 2051-2080, 2071-2100
Heat-related	Fire index (FFDI)	CRA Model	Yearly maximum bushfire index (90th percentile of 30-year data). Index over 50 is considered severe.	1961-1990 (baseline), 2021-2050, 2051-2080, 2071-2100
Heat-related	Number of days with Fire index over 25 (very high category)	CRA Model	Number of days per year with bushfire index exceeding 25 (90th percentile of 30-year data).	1961-1990 (baseline), 2021-2050, 2051-2080, 2071-2100
Precipitation-related	Duration of heavy-rain periods	NARCliM 1.5 + CRA Model	It is a maximum (over 20 years) duration of heavy-rain periods. The Heavy-rain period refers to consecutive days when rainfall exceeded 30mm/day (prolonged periods of heavy rainfall increase the likelihood of flooding).	1961-1990 (baseline), 2021-2050, 2051-2080, 2071-2100
Precipitation-related	Number of heavy-rain periods	NARCliM 1.5 + CRA Model	Mean number of heavy-rain periods. The Heavy-rain period refers to consecutive days when rainfall exceeded 30mm/day (more heavy-rainfall periods can lead to more frequent flooding.)	1961-1990 (baseline), 2021-2050, 2051-2080, 2071-2100
Precipitation-related	Total amount of rain per a heavy-rain period	NARCliM 1.5 + CRA Model	Total amount of precipitation during consecutive rain days (90th percentile of 30-year data).	1961-1990 (baseline), 2021-2050, 2051-2080, 2071-2100
Precipitation-related	Precipitation rate, mm/h	NARCliM 1.5 + CRA Model	Daily precipitation rate recorded (90th percentile of 30-year data).	1961-1990 (baseline),

Type	Climate indicator	Source	Description	Time period
				2021-2050, 2051-2080, 2071-2100
Precipitation-related	Daily precipitation, mm/d	NARCliM 1.5 + CRA Model	Daily precipitation recorded (90th percentile of 30-year data). Not to be confused with rainfall intensity that is measured in mm/hour	1961-1990 (baseline), 2021-2050, 2051-2080, 2071-2100
Precipitation-related	Maximum number of days with rainfall intensity over 25mm/h	NARCliM 1.5 + CRA Model	Maximum number of days in a year when rainfall intensity exceeds 25 mm/h (90th percentile of 30-year data).	1961-1990 (baseline), 2021-2050, 2051-2080, 2071-2100
Precipitation-related	Hail	Lesli and Buckley, 2008	Due to a lack of data, we use the overall number for hailstorm increase in Sydney.	Not directly included in 'CRA Tool 1' because projections are only NSW-wide (cannot be location-specific). The NSW projections are added in 'CRA Tool 2: Risk Level'
Drought-related	Drought duration, days	NARCliM 1.5 + CRA Model	Duration of drought (90th percentile of 30-year data). Drought here is defined as more than 14 consecutive days with rainfall below 1 mm/day).	1961-1990 (baseline), 2021-2050, 2051-2080, 2071-2100
Drought-related	Number of drought periods (no rain for over 2 weeks)	NARCliM 1.5 + CRA Model	Number of drought periods (90th percentile of 30-year data). . Drought here is defined as more than 14 consecutive days with rainfall below 1 mm/day).	1961-1990 (baseline), 2021-2050, 2051-2080, 2071-2100
Drought-related	Number of days with soil moisture below 20%	NARCliM 1.5 + CRA Model	Number of days per year with soil moisture below 20% (90th percentile of 30-year data). Dry soil can increase the likelihood of soil cracking.	1961-1990 (baseline), 2021-2050, 2051-2080, 2071-2100
Other	Lightning	Climate Council, 2016	Due to a lack of data, we use the overall number for storm increase on the East Coast.	Not directly included in 'CRA Tool 1' because

Type	Climate indicator	Source	Description	Time period
				projections are only NSW-wide (cannot be location-specific). The NSW projections are added in 'CRA Tool 2: Risk Level.'
Other	Maximum wind (wind gust), mm/h	NARCliM 1.0 + CRA Model	Maximum per hour wind speed (90th percentile of 30-year data).	1961-1990 (baseline), 2021-2050, 2051-2080, 2071-2100
Other	Number of days with wind speed over 65km/h	NARCliM 1.0 + CRA Model	Number of days per year when wind speed exceeds 65km/h (90th percentile of 30-year data).	1961-1990 (baseline), 2021-2050, 2051-2080, 2071-2100
Other	Mean sea level rise, m	Climate Analytics + CRA Model (to determine whether a location is coastal or not)	Sea level rise according to the mid-value of the prediction range. The location is considered to be 'not coastal' if it's not located within 2km from the coast. The sea level rise data do not include storm surge level.	Projections are available for any time period from the model, but the tool includes only 2039 and 2079 and 2100 for consistency with other parameters in the tool
Other	Maximum sea level rise, m	Climate Analytics + CRA Model (to determine whether a location is coastal or not)	Sea level rise according to the maximum value of the prediction range. The location is considered to be 'not coastal' if it's not located within 2km from the coast. The sea level rise data do not include storm surge level.	Projections are available for any time period from the model, but the tool includes only 2039 and 2079 and 2100 for consistency with other parameters in the tool

Appendix 2: TfNSW CRA Tools vs ISCA CRA Requirements

The tools meet ISCA 1.2 and ISCA 2.0 criteria for climate change risk assessment:

Table A2. CRA Tool versus ISCA requirements

ISCA	Credit	Level	ISCA requirements	TfNSW CRA Tools
ISCA Technical Manual 1.2	Cli-1	Level 1	The scenarios used by the applicant should be sourced from IPCC endorsed Global Circulation Models (GCMs) and may include CSIRO, State or Federal climate projections or a more detailed climate modelling software. The Assessor must justify the selection of the emissions scenario/s and climate change projections used.	NARCliM has been used to construct this model because it provides more granularity in data selection, the highest resolution, and the means to obtain raw climate data. NARCliM uses IPCC endorsed GCMs.
ISCA Technical Manual 1.2 and Manual 2.0	Cli-1 and Res-2	Level 1	A readily available climate change projection is identified and adopted for the asset region over the forecast useful life of the asset.	The tools use projections specific to the region and the asset location. It provides near-future and far-future projections suitable for different assets' lifetime.
ISCA Technical Manual 1.2	Cli-1	Level 1	Direct climate change risks to the asset over the forecast useful life are identified and assessed.	CRA Tool 2 includes both direct and indirect risks assessment.
ISCA Technical Manual 1.2	Cli-1	Level 2	It is expected that a number of published climate change projections for the asset's region at the end of its forecast useful life would be adopted, providing a suitable range of estimates. Again, these selections must be justified.	The tools are built on 12 climate change projections provided within NARCliM. Our models develop single projections by overlaying all 12 projections and calculating each geographical location's maximum. The tool provides a unique projection value for each asset location by interpolating the data (using the nearest neighbour method).

ISCA	Credit	Level	ISCA requirements	TfNSW CRA Tools
ISCA Technical Manual 1.2	Cli-1	Level 2	The climate change risk assessment must be broadened to cover indirect risks.	CRA Tool 2 and the incorporated risk library include assessing both direct and indirect risks. For each risk statement added in the tool, a risk type (direct/indirect) must be provided.
ISCA Technical Manual 1.2 And Manual 2.0	Cli-2	Level 1	Adaptation options to treat all extreme and high priority climate change risks are identified, assessed and appropriate measures implemented.	The library included in the tools provides a list of potential adaptation measures for each risk statement. The assessment consists of selecting appropriate adaptation measures and describing how the proposed adaptation measures can mitigate the risk.
ISCA Technical Manual 1.2	Cli-2	Level 2	Adaptation options to treat 25-50% of all medium priority climate change risks are identified, assessed and appropriate measures implemented.	CRA Tool 2 includes an algorithm for identifying residual risks and a risk summary highlighting how many 'Medium', "High' and "Very High' risks were reduced.
ISCA Technical Manual 2.0	Res-2, Design	Level 1	For climate change projections, detail of the adopted projection including year and data source must be provided.	The details of the projections, source and year used in the TfNSW CRA tool are provided in the Tool Manual.
ISCA Technical Manual 2.0 + ISv2.0 Climate and Natural Hazard Risk Guideline	Res-2, Design	Level 1	As a minimum, the following climate change and natural hazards impacts must be considered in the climate and natural hazard risk assessment process: Air temperature, humidity, sea surface temperature, precipitation, sea level rise, wind and hail, bushfire, coastal inundation, cyclones/storms, flooding, heatwave, drought, frost	The tools directly or indirectly include all of the described climate variables.

ISCA	Credit	Level	ISCA requirements	TfNSW CRA Tools
ISCA Tool – Rulings, v2.0			Projections based on RCP 8.5 must be used.	RCP 8.5 projections were used in the construction of this model.
ISv2.0 Climate and Natural Hazard Risk Guideline			Risk statements must be developed for all climate variables relevant to the project	The tools enable a link between each of the climate variables and risk statement as well as adding risk statements for each of the variables.

Appendix 3: Raw climate data download

It is recommended to use NARCliM due to its finer horizontal resolution; however, specific time horizons are not available in NARCliM 1.0, in which case the CSIRO model can be used as an addition. Note that this issue is not present in NARCliM 1.5, and it is preferable to use it once it becomes available.
To download NARCliM gridded data, you need to register (free).

NARCliM raw data download:

Step 1	To download the data go to https://climatedata.environment.nsw.gov.au/ Go to "Access data", then "Start a data collection", and create a name for the collection
Step 2	Press "New data request" and enter a name. Select NARCliM – GCM forcing as the dataset of choice.
Step 3	**Data type** Choose Domain: South East Australia @ 10km Request type: Gridded data.
Step 4	**Select simulations** Download all 12 ensembles (4 GCMs + 3 RCMs)
Step 5	**Select region** Select the interpolation method: Here you need to define the interpolation method: bilinear or nearest neighbour. The bilinear method tends to smooth temporal variability and extremes. The nearest neighbour preserves them (although it doesn't account for the displacement between the site and model grid). It's more important to keep the extremes and temporal variability for our purposes; therefore, it is better to select the nearest neighbour option. Then select the region that covers all the project assets.
Step 6	**Select time period** Select all three time periods Temporal resolution: daily
Step 7	**Select climate variables** Precipitation accumulation - bias-corrected (pracc_bc) Mean surface air temperature (tasmean) Mean near-surface wind speed (wssmean) Daily maximum surface air temperature - bias-corrected (tasmax_bc) Daily minimum surface air temperature - bias-corrected (tasmin_bc)
Step 8	**Data format** ASCII Grid takes about 30 min to download and can be opened using ArcMap software.

If using the CSIRO model, consideration needs to be made for which model better represents a selected climate variable. The following models can be used:
Extreme temperatures in East Australia: HadGEM2-AO, ACCESS1-0, HadGEM2-ES

Extreme rainfall in East Australia: EC-EARTH, MPI-ESM-MR, HadGEM2-AO
Extreme wind in East Australia: GFDL-CM3, HadGEM2-ES, ACCESS1-0

Appendix 4: NARCliM and CSIRO models specification

Table A3. NARCliM and CSIRO models specification

Specifications:	NARCliM 1.0	Climate futures (CSIRO)
Website	About NARCliM	Climate Future projections tool
Link for data download	NARCliM raw data	CSIRO raw data
Last updated	2021	2015
Number of GCMs used	3	40
Number of available projection ensembles (GCM + downscaling)	6	40
Horizontal resolution for NSW	10 km	25 km
Relevant climate variables available for downloading	Daily mean surface air temperature Daily maximum surface air temperature Daily minimum temperature Daily rainfall Daily mean near-surface wind Daily mean soil moisture Evapotranspiration Humidity	Temperature Maximum temperature Minimum temperature Rainfall Wind speed Humidity Evapotranspiration
Variables that are not included directly in the model but can be viewed online	Number of days a year FFDI > 50	Sea level rise
Baseline period (reanalysis data)	1951 to 2005 (any)	1986 to 2005

Specifications:	NARCliM 1.0	Climate futures (CSIRO)
Time horizons	2020 to 2100 (any)	2025 (2015-2034) 2030 (2020-2039) 2035 (2025-2044) 2040 (2030-2049) 2045 (2035-2054) 2050 (2040-2059) 2055 (2045-2064) 2060 (2050-2069) 2065 (2055-2074) 2070 (2060-2079) 2075 (2065-2084) 2080 (2070-2089) 2085 (2075-2094) 2090 (2080-2099)
Raw data format to be used:	ASCII, NetCDF	ASCII, NetCDF

Appendix 5: Historical financial impacts from extreme weather in NSW[4]

Table A4. Normalised cost natural disasters NSW[53]

Hailstorm		$12,416,411,578
1974	Metropolitan Sydney Hailstorm	$566,004,187
1976	Western Sydney Hailstorm	$749,612,517
1986	Hail	$217,121,743
1990	Northern Sydney Hailstorm	$1,681,692,745
1990	Sydney Hailstorms	$52,717,641
1990	Dubbo Hailstorms	$49,416,509
1992	Western Sydney Hailstorm	$749,612,517
1996	Singleton Hailstorm	$172,628,588
1996	Armidale Hailstorm	$348,433,444
1999	Eastern Sydney Hailstorm	$5,574,498,958
2001	Armidale Hailstorm	$348,433,444
2005	Singleton Hailstorm	$16,431,821
2006	Hunter Valley Hailstorm	$75,720,778
2007	Blacktown Hailstorm	$586,787,347
2007	Lismore Hailstorm	$135,008,911
2015	Anzac Day Sydney Hailstorm	$470,819,649
2016	November Hailstorm	$621,470,779
Cyclone		$7,366,080,282
1967	Cyclone BARBARA	$530,607,847
1967	Cyclone ELAINE	$2,129,012,567
1970	East Coast Low	$217,830,628
1974	Cyclone ZOE	$507,784,688
1978	East Coast Low	$217,830,628
1990	Cyclone Nancy	$238,769,416
1996	East Coast Low	$217,830,628
2003	East Coast Low	$217,830,628
2005	East Coast Low	$217,830,628
2007	East Coast Low	$217,830,628
2015	East Coast Low	$217,830,628
2016	East Coast Low	$217,830,628
2016	East Coast Low	$217,830,628
2017	East Coast Low	$217,830,628
2017	Cyclone Debbie	$1,781,599,484
Wind/storm		$4,613,032,175
1977	Western Sydney Storms	$281,104,694

1978	Western Sydney Storms	$281,104,694
1978	NSW North Coast Storm	$125,919,972
1984	Sydney Floods	$712,680,044
1990	Sydney Storms	$44,085,251
1991	Severe Storms Eden Monaro	$72,767,538
1991	Sydney Region Storms	$1,044,941,850
1994	Blue Mountains Severe Weather	$127,668,342
1995	Hunter Valley Severe Storms	$49,813,888
1996	Storm	$32,791,170
1996	Hunter and New England Storms	$33,906,226
1997	SE NSW Severe Storms	$48,990,647
1997	Sydney Storms	$44,085,251
1997	Grafton Storm	$15,734,579
1998	Nyngan Storm	$35,677,492
1998	Storm	$32,791,170
1998	Sydney Storms	$44,085,251
1998	Sydney Storms	$44,085,251
1998	Hunter Valley Storms	$53,299,486
1999	Illawarra Storm	$129,987,154
2001	Storm	$32,791,170
2001	Storm, Tornado	$72,246,158
2001	Sydney Severe Storm Event	$31,468,091
2001	Dubbo Severe Storm Event	$39,284,641
2001	Casino Severe Storm Event	$80,667,832
2002	Sydney Region Severe Storm	$45,008,993
2002	Northern Rivers Severe Storm	$34,288,222
2004	Casino Severe Weather	$57,213,066
2005	Southern States Severe Weather	$402,020,843
2005	Broken Hill Severe Storm	$15,564,659
2006	Tornado La Perouse	$2,975,462
2007	Tornado Dunoon	$12,387,416
2007	Wagga Severe Storms	$8,423,741
2011	Whitton Tornado	$113,023
2011	Red Rock Tornado	$1,041,978
2011	WA Storms	$241,743,627
2013	New England Tornado Cluster	$1,138,222
2015	Tornado Cluster Illawarra Region	$8,549,324
2015	Tornado Kurnell	$220,291,454
2016	Western Sydney Severe Storm	$19,267,512
2016	NSW Severe Storms	$20,870,661
2016	Severe Weather New South Wales	$5,339,252

2016	Western and Southern Sydney Severe Weather	$4,816,878
Bushfire		$3,320,331,880
1968	Blue Mountains Bushfire	$94,878,693
1983	Bushfire Ash Wednesday	$117,230,194
1984	NSW Bushfires	$1,040,599
1987	Southern NSW Bushfires	$40,425,399
1991	Central Coast Bushfires	$61,214,351
1997	Menai Bushfire	$11,021,313
2001	Bushfire	$166,968,846
2002	Southern Sydney Bushfire	$54,957,304
2003	Alpine Bushfires	$31,442,075
2013	Warrumbungle Bushfires	$39,169,402
2013	Blue Mountains Bushfires	$217,413,271
2016	NSW Bushfires	$1,040,599
2017	NSW Bushfires	$1,040,599
2018	Tathra Bushfires	$82,489,235
2019	2019/20 Bushfires (NSW,QLD,SA,VIC)	$2,400,000,000
Flooding		$2,189,226,605
1974	Western Sydney Flood	$566,004,187
1975	Central Coast Flooding	$407,414,691
1977	Grafton Region Flooding	$108,798,671
1988	Northern Rivers Flooding	$215,191,679
1990	Northern NSW and SW QLD Flooding	$118,155,407
1996	SEQ and Northern Rivers Flooding	$154,318,866
1996	Coffs Harbour Storm	$132,028,884
2001	North Coast NSW Floods and Storms	$118,024,192
2008	Northern Rivers Flood	$21,221,137
2009	NSW Coastal Flooding	$53,851,899
2012	NSW Flooding Event	$149,197,371
2013	NSW Flooding Ex Cyclone Oswald	$139,906,160
2016	Western NSW Flooding	$5,113,461

Appendix 6: Weather-related incidents in NSW and QLD

Table A5. Weather-related incidents in NSW and QLD, Bushfires

	**Woolooga, QLD** September 2018 Impact of the Central Queensland bushfires (temperatures above 40 degrees and wind gusts of up to 40 kilometres per hour made for dangerous and unpredictable conditions)		**North Coast Rail Line, NSW** October 2019 a part of the line damaged in fires
The Blue Mountains rail line between Lithgow and Mount Victoria, NSW January 2020 Extensive damage to power and signalling equipment from massive bushfires		**Bells Line of Road, NSW** January 2020 Bushfire Damage	

Table A6. Weather-related incidents in NSW and QLD, Heatwaves

[Nunga (near Ouyen), VIC]

9 November 2015

Track buckling due to the heat caused derailment of freight train 9150

[Western Sydney, NSW]

December 2017

70 heat-related incidents across the state

[Oxley Highway near Wauchope, NSW]

January 2019

Melting in an extreme summer heatwave (temperature over 45C) sweeping New South Wales

[Malanda Millaa Millaa Road, QLD]

July 2018

Bitumen melting causing inches of bitumen coating drivers' tyres

Table A7. Weather-related incidents in NSW and QLD, Flood

	**Lewisham train station, NSW** 2012, 2014, 2015, 2018 Flooding due to insufficient capacity in the drainage and pump system		**Mount Isa line, QLD** February 2019 Flooding after around one week of heavy monsoonal rain in north-west Queensland
Katoomba Station, NSW January 2019 Both pump units in the station's subway had failed during the storm, causing water to recede at a slower rate than usual.		**Julia Creek QLD** December 2015	

Table A8. Weather-related incidents in NSW and QLD, Storm and landslide

	**Mt Jukes, QLD** March 2012 The landslide blocked Seaforth Rd		**Springbrook's Pine Creek Road, NSW** March 2017 The road has been torn in half, with the area getting the heaviest falls from ex-Cyclone Debbie
Leura, NSW February 2020 The severe rain has also caused a landslip		**The Leichhardt Highway between Banana and Theodore, NSW** January 2011 Severely damaged during Rockhampton floods	

Appendix 7: TfNSW Risk Consequence and Likelihood Tables

Table A9. Risk Consequence Table

Consequence Table						
Rating	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**
Description	**Insignificant**	**Minor**	**Moderate**	**Major**	**Severe**	**Catastrophic**
Safety	-Incident and/or injury/illness to staff/customer/community, not requiring first aid or medical treatment -No lost time	-Injury or illness to staff/customer/ community, requiring first aid or medical treatment (non-hospitalisation) -No lost time post medical treatment -Single event	-Minor injuries or illnesses to staff/customer/community, requiring professional medical treatment (i.e. Doctor, nurse, and paramedic) or hospitalisation resulting in lost time -Injuries to customer/community requiring hospitalisation	-1 to 10 serious injuries or illnesses to staff/customer/community, as defined under S36 of the WHS Act (Work Health and Safety Act 2011 No 10) resulting in hospitalisation, lost time and/or potential permanent impairment -Multiple injuries to customer/community requiring hospitalisation -Single event and/or multiple locations -Co-ordinated emergency response required	-Single fatality and/or 10 to 20 serious injuries or illnesses to staff/customer/ community, as defined under S36 of the WHS Act (Work Health and Safety Act 2011 No 10) resulting in hospitalisation, lost time and/or potential permanent impairment -Could impact safety across the network -Co-ordinated emergency response required	-Multiple fatalities and/or more than 20 serious injuries or illnesses to staff/customer/community, as defined under S36 of the WHS Act (Work Health and Safety Act 2011 No 10) resulting in hospitalisation, lost time and/or potential permanent impairment. (Permanent disabilities/chronic diseases) -Transport unable to assure community and network safety -Co-ordinated emergency response required
Everyday Service Delivery (Customer Satisfaction)	-Isolated written complaints -No impact to overall customer satisfaction index.or customer ratings (Core customer satisfactions drivers). -Typical levels of complaints per 100K boardings benchmark	-Uninterrupted complaints at an increased volume for more than 3 months, resulting in a material increase in the rate of customer complaints for the mode or service (but less than 33% of the normal background level), increased ministerial and potentially ombudsman complaints -No impact to the overall customer satisfaction index; -Relatively small reduction (<5%) in the satisfaction level on one of the core	-Continuous complaints at an increased volume for more than a year, and/or an increase in the rate of customer complaints for the mode or service of >33% of the normal background level (per 100,000 boardings). Increased ministerial and ombudsman complaints and some media coverage. -Reduction in the overall customer satisfaction index for one mode by no more than 2%; Relatively small reduction	-A substantial and sustained uplift in the rate of customer complaints (per 100,000 boardings) with a backlog that can be cleared within 30 days, depending on resources. Repeat complaints associated with a failure to respond in a timely manner. Increased ministerial and Ombudsman complaints, along with intensified media coverage. NB: major changes in services tend to generate	-Increased customer complaints for up to 6 months, with normal background rates for the mode or service increasing by a factor of 3 or more, and a persistent backlog in responses – allowing for typical seasonal variation in complaints volume throughout the year -Backlog of complaints not readily cleared within 30 days, and repeat complaints associated with delayed responses to complaints.	A prolonged increase in customer complaints for greater than 6 months, with normal background rates for the mode or service increasing by a factor of 10 or more, and a persistent backlog in responses - allowing for typical seasonal variation in complaints volume throughout the year. -Substantial backlog of complaints. -Ministerial and Ombudsman complaints. - Persistent media and political scrutiny.

Consequence Table						
Rating	C6	C5	C4	C3	C2	C1
Description	Insignificant	Minor	Moderate	Major	Severe	Catastrophic
		drivers of customer satisfaction for no more than a year.	(<5%) in the satisfaction level in 2 or 3 core drivers of customer satisfaction. Relatively small reduction (<5%) in the satisfaction level in 2 or 3 core drivers of customer satisfaction.	customer complaints (e.g. NorthWest Bus Service changes in Jul 19). In some instances this may present a risk while in others it may represent an adjustment period for customers. -Reduction in the overall customer satisfaction index for any mode by no more than 2% and can be recovered within 12 months. -Small reduction (<5%) in the satisfaction level for more than 3 core drivers of customer satisfaction or more than 5% on any one driver.	-Increased ministerial and Ombudsman complaints, accompanied by persistently negative media coverage. -The overall customer satisfaction index for one major mode only dropping by 3% or more and can be recovered within 12 months. -Larger reduction (5% or more) in the satisfaction level for more than 3 core drivers of customer satisfaction or more than 10% on any one driver.	-A prolonged material reduction in overall customer satisfaction across the board (5% or more) for one or more major transport modes. -A prolonged reduction (10% or more) in the satisfaction levels of the core drivers of customer satisfaction on more than one mode.
Everyday Service Delivery	-Antisocial behaviour on service or resulting in minor delays -Minor traffic incident resulting in minor delays -Passenger(s) unable to disembark due to technical asset failure for more than 5 minutes -BAU service delays	-BAU cancelations of service due to various causes including asset failure -Partial or full closure of a line/route/run or incidents resulting in minor to moderate delays e.g. track failure. -Access and operation compromised (e.g. closed entry and exits) for >30 minutes	-Police Operation on a transport asset (e.g. threat, suspicious package, security incident, civil unrest) -Incident requiring Investigation by statutory authorities (WorkSafe, EPA, ONRSR/OTSI, NSW Police Force, RMS etc.)	-Police Operation on a transport asset (e.g. threat, suspicious package, security incident, civil unrest) resulting in a significant delay for a prolonged period of time and, likely to attract significant media attention e.g. no services during peak periods -Incidents resulting in a significant detrimental impact to a mode or multiple modes of transport for a prolonged period of time in excess of an hour, or likely to attract significant media attention e.g. derailment, overcrowding at stations,	-Serious injury or fatality to member of staff -Fatality on a service or asset / station/ interchange (not self-harm)	-Multiple injuries or fatality due to asset failure / derailment / or significant ongoing threat

Consequence Table						
Rating	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**
Description	**Insignificant**	**Minor**	**Moderate**	**Major**	**Severe**	**Catastrophic**
				significant delays or no services during peak periods, injury to school children, multiple injuries, person overboard, fire on a service -Evacuation or unplanned closure, caused by flood, fire, smoke, or hazardous substance spill, and suspicious substance		
Financial Sustainability	- Capex (above P50 capital budget) < $10 million - Non-infrastructure Capex <$100K - Opex (including accounting adjustments) <$1 million - Revenue (including fines, penalties, compensation etc) <$100K	- Capex (above P50 capital budget) $10 million to $25 million - Non-infrastructure Capex $100K to $1 million - Opex (including accounting adjustments) $1 million to $10 million - Revenue (including fines, penalties, compensation etc) $100K to $1 million	- Capex (above P50 capital budget) $25 million to $50 million - Non-infrastructure Capex $1 million to $5 million - Opex (including accounting adjustments) $10 million to $25 million - Revenue (including fines, penalties, compensation etc) $1 million to $5 million	- Capex (above P50 capital budget) $50 million to $150 million - Non-infrastructure Capex $5 million to $25 million - Opex (including accounting adjustments) $25 million to $75 million - Revenue (including fines, penalties, compensation etc) $5 million to $25 million	- Capex (above P50 capital budget) $150 million to $250 million - Non-infrastructure Capex $25 million to $50 million - Opex (including accounting adjustments) $75 million to $150 million - Revenue (including fines, penalties, compensation etc) $25 million to $50 million	- Capex (above P50 capital budget) >$250 million - Non-infrastructure Capex >$50 million - Opex (including accounting adjustments) >$150 million - Revenue (including fines, penalties, compensation etc) >$50 million
Reputation and Integrity	-Single negative article in local media -Limited social media commentary -Goodwill, confidence and trust retained -Confined to the Branch -Local council may want to discuss	-Series of negative articles in local media (District / electorate based adverse media) -Some social media commentary -Confidence remains - minor loss of goodwill. Confined to Branch but requiring notification to Division -Council requires written explanation -Recoverable with little effort or cost. Some continuing	-Extended local media coverage with some broader Regional media coverage -Extended negative social media coverage -Confidence and trust of stakeholders dented (recoverable at modest cost within existing budget and resources) -Division formal response needed to State - Government/Regulator	-State media coverage, short term negative national media coverage -Widespread social media coverage -Confidence/trust impaired -Project/activity credibility under question -TfNSW and/or Ministers Department requires update	-Sustained negative State media coverage -Regular 'talk-back' programs questioning credibility and capability -Confidence and trust are severely damaged -Widespread negative social media coverage -Regular updates demanded by Minister -Stakeholders withdraw their support recoverable at considerable cost, time and staff effort.	-Sustained, high profile media attention at National level -Material change in the public perception of the Agency -Extensive negative social media coverage -Confidence and trust non-existing. Government forced to reverse decision -Stakeholders are actively campaigning against the organisation

Consequence Table						
Rating	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**
Description	**Insignificant**	**Minor**	**Moderate**	**Major**	**Severe**	**Catastrophic**
		scrutiny/attention				
People	-Little employee interest/impact -Confidence and trust of employees retained -Confined to small number of people < 5 -No performance impairment -Little or no impact on workload, employee numbers, work/life balance -No cultural impact -No noticeable excess stress or excessive absenteeism of key staff during/after workload peaks - Union activity/correspondence without staff pickup	-Impacts employees at a specific location and/or of a specific discipline (e.g. accountants) (<50) -Employees concerned as to their wellbeing and future -Employees frustrated but still willing to proactively contribute to meeting objectives -Isolated incidence of excess stress or excessive absenteeism of key staff during/after workload peaks - Unions are being called upon to take up employee cause – IR tension is high	-Impacts large numbers of employees (<500) -Employee's wellbeing and future is at risk -Employees frustrated and are largely only 'doing what needs to be done' -Culture and morale dropping -People are actively looking to leave -Noticeable incidence of excess stress or excessive absenteeism of key staff during/after workload peaks - Pockets of staff support for union agitation	-Majority of employees potentially impacted (50%). Employee morale is low -Employees not willing to proactively engage – lack of commitment -Key people are actively looking to leave - Widespread staff support for union agitation -Widespread incidence of excess stress or excessive absenteeism of key staff	-All employees potentially impacted -Employee morale is poor -Employees not willing to proactively engage -Key people are leaving, workforce churn rates increase (loss of IP) -Unions action – work to rule, stop work, short time but significant action -Stress and other work related injuries/health issues increasing -High incidence of excessive absenteeism of staff	-Employee brand significantly impaired -All employees potentially impacted -No confidence and trust of employees -Transport wide dissatisfaction – bad, dysfunctional morale. -Performance significantly impaired – little or no immediate sign of improvement -High staff turnover – poor corporate culture -Doubling of workload, stress levels dangerously high -Long-term (months) of ongoing rolling industrial action which significantly impacts on service delivery
Project Delivery	-Insignificant delay (1 – 2 days) -No reduction in functionality/scope -No discernible impact, benefit realisation may have a slight decrease but largely intact -No time delay with initiative or project but it will incur a slight decrease in the benefits realised -<2 month project delay	-Insignificant delay (1 – 2 days) -No reduction in functionality/scope -No discernible impact -Benefit realisation partially impaired but still adds value and economically sound -No public impacts -2-3 month project delay	-Minor delay (<1% to max of 1 week) -< 1% reduction in functionality/scope -Benefit realisation partially impaired but still adds value and economically sound -No public impacts -3-6 month project delay	-Major delay (< 10% to max of 5 months) -< 10% reduction in functionality/scope -Cost/benefit analysis may not have supported the Program go ahead -Publicly announced portion/milestone missed or final completion date missed with demonstrable mitigating external circumstances -6-9 month project delay	-Severe delay (< 15% to max of 9 months) -< 15% reduction in functionality/scope -Cost/benefit analysis would not justify program -Publicly announced portion/milestone missed or final completion date missed on critical path project -9-12 month project delay.	-Total blow out in time (> 9 months or > 15%). > 15% reduction in functionality/scope -Will probably require a major project in the foreseeable future to either rectify or complete the results of this project -Publicly announced portion/ milestone significantly missed or final completion date significantly missed on critical path project ->12 mth project delay -Failure to realise benefits

Consequence Table						
Rating	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**
Description	**Insignificant**	**Minor**	**Moderate**	**Major**	**Severe**	**Catastrophic**
						of the initiative
Regulations and Compliance	-Low-level/Technical non-compliance with legal and/or regulatory requirement or duty by individuals or TfNSW- not reportable -Minor non-compliance to a low impact contract clause – little or no interest by either party to pursue or rectify	-Non-compliance with whole or significant aspects of Government policy not reportable but requiring internal activity to put in place -Formal investigation and/or formal notification to regulator -Minor breach of contract by either party rectified through local management discussion	-Non-compliance with key Government policy - reportable and/or explanation required – need to put in place as soon as possible -Non-compliance – key obligation -Formal notification to regulator -Agency on notice -Breach of contract by either party rectified at Branch level management discussion -Small fine and no disruption to services.	-Technical non-compliance with a minor Government Policy - not reportable -Low level non-compliance -Technical non-conformance -Minor non-compliance to a low impact contract clause – little or no interest by either party to pursue or rectify -Substantial fine and no disruption to services	-Non-compliance with high profile, outward facing Government policy or Ministerial decree - immediately reportable to Government body (e.g. Treasury) and action to put in place required immediately (high priority) -Continuous breach resulting in prohibition notices -Breach of significant, key aspects of contract by either party leading to lodgement (threat) to sue and recompense at severe financial levels -Cessation of contract may occur -Large fines as a result of non-compliance -Licence or accreditation restricted or conditional affecting ability to operate	-Non-compliance with high profile Government policy or Ministerial decree - immediately reportable to Ministerial level requiring actions to put in place immediately (high priority) and progress to be reported to the Minister on an agreed and appropriate schedule -Litigation and potentially imprisonment -Loss of Operating licenses -Continued breach cannot be tolerated -Major contract breach by either party leading to significant litigation and financial costs -Total breakdown and cessation of contract -Criminal prosecution as a result of non-compliance
Environment	-No appreciable changes to environment	-Change from existing conditions that can be rectified immediately (< 1 day) with available resources	-Short-term (< 1 year) and/or well-contained environmental impact -Minor remedial actions probably required	-Short to medium term (between 1 and <5 years) environmental impact -Considerable remedial actions probably required	-Medium-term (>5 years) environmental impact -Extensive remedial actions probably required	-Long-term (>10 years) large-scale environmental impact -Extensive and ongoing remedial actions probably required

Table A10: Risk Likelihood Table

Rating	L6	L5	L4	L3	L2	L1
Descriptor	Almost Unprecedented	Very Unlikely	Unlikely	Likely	Very Likely	Almost Certain
Qualitative Expectation	-Not expected to ever occur during time of activity or project -There is very little or no real chance of this risk occurring -History shows that this risk hardly ever happens, if at all	-Not expected to occur during the time of activity or project -There is only an unusual chance of this risk occurring -History shows that this risk rarely happens, usually under unusual circumstances	-More likely not to occur than occur during time of activity or project -There is a chance of this risk occurring but not very often -History shows that this risk does happen but not very frequently	-More likely to occur than not occur during time of activity or project -There is a chance of this risk occurring in the current period -History shows that the risk has occurred on a number of occasions	-Expected to occur occasionally during time of activity or project -There is a good chance of this risk occurring -History shows that the risk occurs unacceptably too often	-Expected to occur frequently during time of activity or project -There is a very strong chance of this risk occurring -History shows that it is something that occurs frequently
Quantitative Frequency	Risk event will occur at least once every 50 Years	Risk event will occur at least once every 25 Years	Risk event will occur at least once every 10 Years	Risk event will occur once every year	Risk event will occur between 2 and 10 times per year	Risk event will occur more than 10 times every year
	Less than 2% probability of risk/event occurring within the next 12 months	Greater than 2% and up to 4% probability of risk/event occurring within the next 12 months	Greater than 4% and up to 10% probability of risk/event occurring within the next 12 months	Greater than 10% and up to 50% probability of risk/event occurring within the next 12 months	Greater than 50% and up to 80% probability of risk/event occurring within the next 12 months	Greater than 80% probability of risk/event occurring within the next 12 months