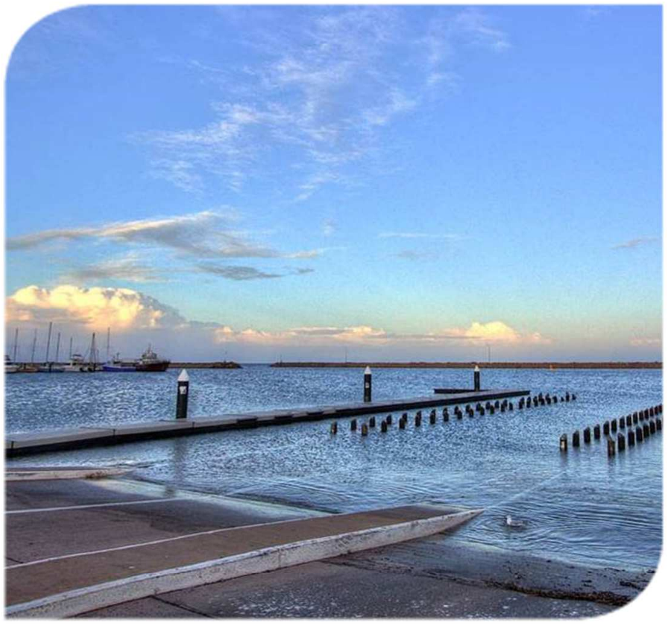
Climate Change Adaptation Guideline



Government of South Australia
Department for Infrastructure and Transport

Climate Change Adaptation Guideline

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This revised Guideline has been prepared with support from Edge Environment. It has been approved and authorised for use by Departmental staff and its authorised agents by:

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Front cover images (clockwise from top left):
King tide at Whyalla boat ramp (source: Whyalla News, 10 July 2014)
Flood damage to Andamooka-Olympic Dam Rd, April 2010
Bangor bushfire, February 2014
King tide at Henley Beach, April 2009 (source: witnesskingtides.org)

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1 Introduction

As a manager of significant State infrastructure with a long asset life, the Department for Infrastructure and Transport (the department) has a responsibility to protect its assets against the potential risks of climate change, and ensure that new buildings and infrastructure are designed to be resilient to future climate conditions. This will assist the communities we service to become more resilient to shocks and stresses by maintaining a safe, operational transport infrastructure network.

Most of the department's assets, services and operations are affected by climate impacts. Key vulnerabilities in the asset portfolio, which may exacerbate the impacts of future climate change, include:

- our infrastructure is designed to function under current temperature ranges, rainfall patterns and sea levels;
- our maintenance programs are based on historic deterioration rates;
- our transport networks cater for current and predicted land use and population distribution; and
- our infrastructure is known to be at risk from a range of extreme weather events that can lead to service disruption or damage to critical assets.

Climate change means that many of these assumptions are no longer valid, so that long-term infrastructure now needs to be designed, constructed and operated to be resilient to hotter, drier and stormier climatic conditions, with higher sea levels.

In 2015 the department adopted a Climate Change Adaptation Strategy, which commits the department to assessing and responding to future climate risks. The Strategy seeks to mainstream the treatment of future climate risk by incorporating it into each business unit's and each program/project manager's ongoing risk management procedures (rather than creating separate discreet processes). In this way, climate risks will be assessed, prioritised, treated and monitored in accordance with the departments overall risk management framework (DP086), which is aligned to AS/NZS ISO 31000:2009.

This Guideline assists staff in the implementation of the Strategy by providing a process for considering future climatic risk and treatment options in the management of the department's projects, assets and operations. It describes when climate change risk should be considered and how treatment (adaptation) options can be identified for the short and long term.

The Climate Change risk assessment components of this guideline are based on AS 5334-2013 – Climate change adaptation for settlements and infrastructure, a risk-based approach.

1.1 South Australian Policy Context

The strategic policy basis for the department's climate change adaptation response is set out in several key state-wide strategic documents. These are summarised in the department's Climate Change Strategy.

In particular, the Government Action Plan for the state's Climate Change Adaptation Framework (2012) requires State Government Agencies to:

- incorporate climate adaptation into all decision-making; and
- manage risks from climate change impacts to government infrastructure and services in such areas as emergency management, transport, land use planning, environment, health services and public housing.

This is being done to varying extents by different agencies. The Development division Planning Policy library (which forms the basis of all Council Development Plans) includes standards controlling development in areas prone to sea level rise and coastal recession.

1.2 Purpose of this document

This guidance document aims to:

- assist departmental staff to undertake a climate change risk assessment for the department's assets, services and operations (to ensure that climate risks can be adequately addressed in decision making)
- reduce the department's liability for loss or damage resulting from climate-related events
- help to avoid potential economic and community disruption and environmental damage
- increase the resilience of the infrastructure network to climate-related shocks and stresses to maintain service delivery.

The guide should be employed for climate risk assessment of the following asset groups:

- **Existing assets and programs** within the department
- **New assets** proposed through the planning of future projects

1.3 Who should use it?

- All staff involved in business risk assessment
- Staff and contractors involved in the planning and design of projects and programs.

Identification and assessment of climate change impacts should inform business case development and initial risk assessment for projects, and potential treatment options should be considered along with other design alternatives which inform preliminary planning and design.

1.4 When should the climate change assessment be undertaken?

1.4.1 Existing infrastructure assets

Climate change risks should routinely be considered whenever risk assessments are undertaken for an existing asset. This includes regular, ongoing risk assessments for existing assets and programs, which are undertaken in accordance with DP086 Risk Management Policy;

1.4.2 New infrastructure assets

For a program or project greater than $100million in value and/or in or adjacent a marine or estuarine environment, or where a project will be registered for and IS Rating, a climate change risk assessment should be undertaken during concept development and project initiation/planning phases.

Where a climate change assessment has recently been carried out for a project of a similar nature (i.e. similar location, similar asset elements and design life), it may be appropriate to utilise these assessments to identify applicable climate change risks and mitigation measures for the project. DIT Technical Services Sustainability team should be consulted to provide advice and access to the risk assessment as appropriate.

Programs and projects undergoing an IS rating should also cross check any ISCA credit requirements related to assessing and mitigating climate change risk.

Where the above criteria does not apply and previous assessment is not available, for programs or projects greater than $15 million in value, the sensitivity screening in section 2 should be applied to determine whether a climate change risk assessment should be undertaken.

This 'pre-screening' process is summarised in Figure 1 (Step 1a).

1.5 Where should the outcomes be recorded?

The same process should be followed for climate change risks as for any other risks identified and managed by departmental staff, i.e.:

- Organisational risks are recorded in the Corporate Risk Register or in risk databases maintained by business units (eg OrgRisk);

- Risks and treatment options identified during the initiation and planning phases for new projects and programs should be documented as part of the project business case and the Project Definition Report. They should also be recorded in the project's risk register, and reviewed and updated as the project progresses.

A template is provided in Appendix 1 to assist in documenting the climate change assessment. It is strongly suggested that this is employed when reporting on a climate risk assessment for a DIT asset. Also included in Appendix 2 is a Climate Change Risk Assessment Checklist, which must be completed when undertaking assessments using this Guideline and submitted with assessment reports as an Appendix. The purpose of this checklist is to ensure that all mandatory tasks required by DIT in undertaking a climate change assessment have been completed.

An overview of the climate change assessment process is shown in Figure 1.

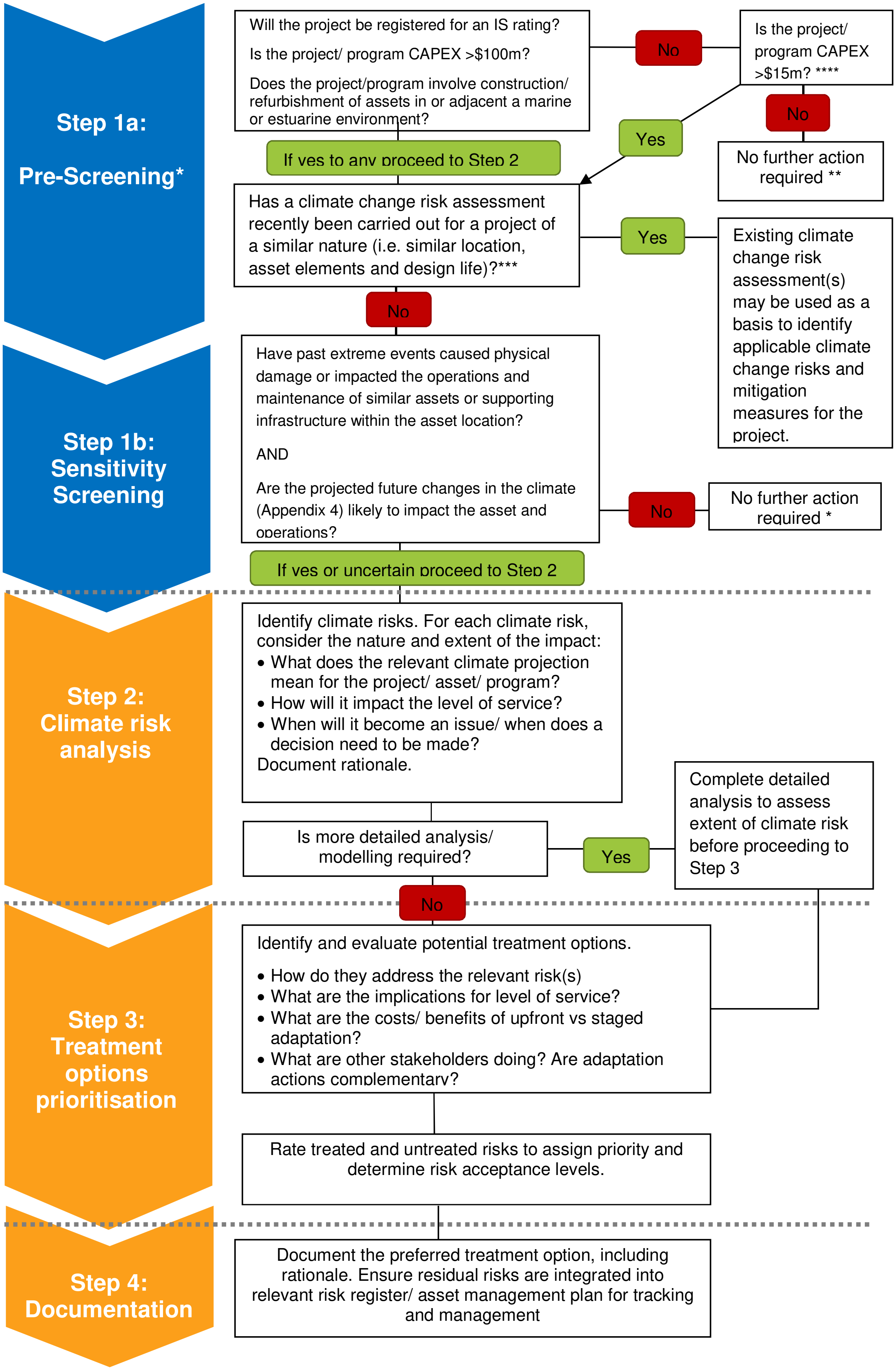


Figure 1 Overview and decision tree of the department's climate change assessment process

* Step 1a ‘Pre-Screening’ applies only to projects being delivered under the DIT Master Specification for Transport Infrastructure

** DIT Technical Services will undertake an annual review of completed Climate Change Risk Assessments to identify any high risks and liaise with relevant technical leads to implement them (where they haven’t already been actioned). In any subsequent risk assessments which identify similar risks, the inherent risk should then be rating medium or lower as there is already an adequate control/ measure in place.

***DIT Technical Services Sustainability team should be consulted to provide advice and access to the risk assessment as appropriate.

**** Consistent with the trigger for Cabinet consideration, > $15 million applies to construction costs and is inclusive GST.

2 Assessment Step 1b: Sensitivity screening

2.1 Screening for direct and indirect climate sensitivities

Both stresses and shocks related to future climate impacts may directly and indirectly affect the design and operation of various DIT assets and programs. The tables below summarise examples of direct and indirect climate impacts on various DIT assets and programs.

Table 1 – Summary of example direct risks from temperature extremes on a selection of DIT assets / programs.

Asset / Program	Direct risks - temperature extremes	
	Stresses	Shocks
Roads	Increased wear and tear of spray sealed surfaces and reduced asset lifetime	Extreme heat leading to direct damage to road surface
Rail program	Reduced overall passenger comfort due to increased temperatures	Impacts of scheduling of construction/ maintenance work
Buildings	Increased operational costs due to increased loads on air conditioning systems	Inability for air conditioning to maintain thermal comfort

Infrastructure assets and programs exist within and depend upon a wider network of supporting assets and systems. Climate change impacts on this network may have important indirect implications for the resilience of the asset being assessed and should therefore be identified and managed where possible.

The Infrastructure Sustainability Council of Australia (2018) describes indirect climate risks as impacts on another system or asset that may disrupt the operational capacity of the asset being assessed. Indirect risks can be upstream, internal or downstream, as described below:

Table 2 – Summary of indirect risk types and key examples.

Indirect risk type	Description	Risk examples
Upstream	The products or services provided to one infrastructure by another external infrastructure that are necessary to support its operations and functions.	Failure of local power supply during severe storm or heatwave leading to loss of asset service delivery.
Internal	The interactions among internal operations, functions, and missions of the infrastructure. Internal dependencies are the internal links among the assets constituting a critical infrastructure	Drought related drying of the water well at an electricity generating plant, leading to reduced operating capacity.
Downstream	The consequences to a critical infrastructure's consumers or recipients from the degradation of the resources provided by a critical infrastructure.	Closure of a road asset due to flooding impacts leading to increased traffic flows on alternate routes.

Adapted from Rinaldi, S.M., J.P. Peerenboom, and T.K. Kelly, 2001 in ISCA (2018)

The first step in determining whether to undertake a climate change assessment is to determine whether the project/asset/program is sensitive to climate impacts, and therefore potentially susceptible to climate change. For new projects/ assets and existing assets, the following should be assessed.

1. Have past extreme events caused physical damage or impacted the operations and maintenance of similar assets or supporting infrastructure within the asset location? If any past or current impacts from extreme events have been identified, are projected future changes in the climate (available at Appendix 4) likely to impact the asset and operations? If yes, or there is uncertainty, the assessment should progress to **assessment** step 2.

2. For existing assets, if the asset location has previously recorded impacts, is it anticipated that the future asset design can avoid or mitigate the risks from those impacts, and can adaptation responses be cost effectively retrofitted in the future? If no, or there is uncertainty, the assessment should progress to **assessment** step 2.

If no material sensitivities are identified, the rationale should be documented, and no further action is required.

To support the identification of climate sensitivity, staff assessors may find it useful to review the following sources:

- The summary of climate impacts initially identified by departmental staff in 2011/12 (Findings from climate change workshops held with department staff in 2012, Knet: 9320116)
- The summary of common asset element vulnerabilities for buildings, roads and bridges identified in Appendix 3
- Draw on internal knowledge and experience of the asset/ activity and how it is impacted by climate conditions.

3 Assessment Step 2: Climate Risk Analysis

The aim of climate risk analysis is to identify in detail important climate related risks that can be used to inform adaptation planning. This step must be undertaken by a multi-disciplinary team that has a deep understanding of the asset or program being assessed, and may include (where relevant):

- Risk managers
- Designers (e.g. with backgrounds in flooding, civil and structural design)
- Asset operators and maintenance staff
- Environmental and sustainability staff
- Community relations staff

3.1 Establish the context

Establishing the context of a climate risk assessment determines the scope of what is to be assessed and over what timeframes. This includes defining the key asset or program objectives, climate and regional context.

3.1.1 Define objectives

The objectives of the target asset or service include both internal and external objectives related to its successful operations. Understanding the key operational objectives helps to identify risks that may impact upon these goals.

Objectives should be documented in the Climate Change Risk Assessment Reporting template (Appendix 1).

3.1.2 Identify relevant timeframes and scenarios

Before reviewing climate projections, it is important to consider the design life of the asset, or the timeframe of the program. Climate change projections are generally presented for 2030, 2050, 2070 and 2090. Decision makers must employ the projections for the timeframe(s) relevant to their asset/activity, including asset sub-components.

If assessing an asset with a long design life (over 50 years), climate impacts should be assessed over two different time periods to understand how the risk may change over time, including both short (i.e. 2030) and long-term (i.e. 2090) projections. This can help determine the most effective time to apply identified treatment options. In alignment with the Guide to Climate Projections for Risk Assessment and Planning in South Australia (Green & Pannell, 2020), it is recommended that:

- The RCP 8.5 (high emissions) scenario is used to undertake a climate risk assessment for assets with a lifetime to 2050 or before.
- Both RCP 8.5 and RCP 4.5 emissions scenarios are employed for developing projections for projects with lifespans beyond 2050 to provide a broader range of possible futures against which risks should be assessed.

3.1.3 Review current and future climate information

To understand the historic climate context of the asset or service, Refer to *Section 5 Current climate data* to source current climate data (usually from the Bureau of Meteorology (BoM)). Data should be retrieved from the nearest BoM weather station.

In addition to gathering historic climate data, project teams should also undertake a review of any available natural hazard or disaster studies that can be used to inform risk assessments.

A selection of timeframes and projection scenarios should be documented and included in the Climate Change Risk Assessment Reporting template (Appendix 1). For future climate information, the timeframes identified in the previous task should be used (refer section 3.1.2) along with the most up-to-date projections. At the time of publishing, the most recent projections available are those included in the Guide to Climate Projections for Risk Assessment and Planning in South Australia (Green & Pannell, 2020), which include both Goyder Institute for Water Research's Climate Change Projections for South Australia and the CSIRO and Bureau of Meteorology's Climate Change in Australia climate datasets.

A selection of these projections have been included in Appendix 4, which provides a summary of regional climate projections for South Australia.

For further information, including projections for climate thresholds (e.g. number of days over 40˚C), refer to the CSIRO Climate Change In Australia website[1]. These climate projections would be adequate for an initial assessment of the climate risks relating to the asset or program.

Additional information on the Goyder Institute projections is provided at SA Climate Ready[2], which includes information on regional projections and a portal to access detailed data for the State.

If detailed modelling (including hydrological modelling) is required, the **Goyder Institute** offers more localised climate data for South Australia and is recommended. While it is not mandated for use across all State agencies, the intention is that it be used to provide a consistent approach to decision making around adaptation strategies within South Australia.

3.1.4 Understand the regional context

When assessing risks, particularly long-term risks, it is important to determine whether the context is likely to change in future. Talk to stakeholders and/or refer to regional climate change adaptation plans such as the Regional Climate Adaptation Plan for Eyre Peninsula, Yorke and Mid-North Regional Climate Action Plan to find out whether there are implications for the project/ program[3]. For example, there is no point raising a bridge to guarantee a certain level of flood immunity if the adjoining network will be affected by flooding/ sea level rise.

Some councils have also formed climate change partnerships with other councils, and have undertaken vulnerability assessments, sector agreements and other studies, e.g. Resilient East, AdaptWest and Resilient Hills and Coasts.

Many of the State's regional climate change adaptation plans were developed over the period 2012 to 2016 and are currently being reviewed. As such it is important to speak with local government contacts in particular to determine the status of these plans.

3.2 Identify and assess climate change risks

Once the context is established, findings from the initial screening assessment should be employed to inform the identification and evaluation of risks. The following sections summarise the risk identification and assessment approach.

[1] https://www.climatechangeinaustralia.gov.au/en/
[2] CSIRO Climate Change In Australia website
[3] Regional climate change adaptation plans for South Australia can be found at: https://www.environment.sa.gov.au/topics/climate-change/programs-and-initiatives/adapting-to-climate-change/regional-adaptation-plans

3.2.1 Identify and evaluate risks

Employ the findings of the sensitivity assessment described in step 1 as well as the understanding of the context defined in Section 3.1 to identify climate related risks to the successful operation of the asset or program over its useful life. As mentioned in Section 3.1.2, risks to assets or programs with a long-term design life should be assessed for multiple time periods.

It is helpful to identify risks by assessing specific elements of the asset or program, or by identifying risks across the asset that are associated with a specific climate variable for the region (e.g. increase in annual days over 35˚C).

Holding a workshop with a multidisciplinary team is accepted as industry best practice for identifying and evaluating risks and is strongly recommended, but where this is not possible or practicable, this can be achieved through alternative means such as separate meetings with discipline leads to identify risks relevant to all sensitive aspects of the asset.

Risks should be documented in a risk register to facilitate evaluation.

> CLIMATE CHANGE RISK REGISTER
>
> A risk register template that can be used for climate change risk assessment projects is provided at here. This can be used for recording contextual information, descriptions of climate variables, risk statements, and calculating and recording likelihood, consequence and risk scores.

3.2.2 Assess risks

Once documented, climate risks should be assessed for each relevant time frame (considering the relevant climate projection) using the scales of likelihood and consequence summarised below:

a) Determine the likelihood of a risk arising using Table 3 [4].

b) Determine the level of consequence of a risk arising using Table 4.

c) Determine the level of priority for each risk using Table 5[1].

[4] Tables 5-7 are taken from AS334-2013, and are designed for assessment of climate change risks to infrastructure and settlements. If you are undertaking a risk assessment for something other than infrastructure and settlements, it may be more appropriate to use the likelihood and consequence matrices provided in DP086 Risk Management Policy.

Table 3 - Definitions of risk likelihood (Source: AS5334-2013).

Rating	Descriptor	Recurrent or event risks	Long term risks
Almost certain	Could occur several times per year	Has happened several times in the past year and in each of the previous 5 years *or* Could occur several times per year	Has a greater than 90% chance of occurring in the identified time period if the risk is not mitigated
Likely	May arise about once per year	Has happened at least once in the past year and in each of the previous 5 years *or* May arise about once per year	Has a 60–90% chance of occurring in the identified time period if the risk is not mitigated
Possible	Maybe a couple of times in a generation	Has happened during the past 5 years but not in every year *or* May arise once in 25 years	Has a 40–60% chance of occurring in the identified time period if the risk is not mitigated
Unlikely	Maybe once in a generation	May have occurred once in the last 5 years *or* May arise once in 25 to 50 years	Has a 10–30% chance of occurring in the future if the risk is not mitigated
Rare	Maybe once in a lifetime	Has not occurred in the past 5 years *or* Unlikely during the next 50 years	May occur in exceptional circumstances, i.e. less than 10% chance of occurring in the identified time period if the risk is not mitigated

Table 4 - Definitions of risk consequence (Source: AS5334-2013).

RISK CRITERIA—EXAMPLE OF QUALITATIVE MEASURES OF CONSEQUENCES

Consequence descriptor	Adaptive capacity (see Note 1)	Infrastructure, service	Social/cultural	Governance	Financial (see Note 2)	Environmental (see Note 3)	Economy (see Note 4)
Insignificant	No change to the adaptive capacity	No infrastructure damage, little change to service	No adverse human health effects	No changes to management required	Little financial loss or increase in operating expenses	No adverse effects on natural environment	No effects on the broader economy
Minor	Minor decrease to the adaptive capacity of the asset. Capacity easily restored	Localized infrastructure service disruption No permanent damage. Some minor restoration work required Early renewal of infrastructure by 10–20% Need for new/modified ancillary equipment	Short-term disruption to employees, customers or neighbours Slight adverse human health effects or general amenity issues	General concern raised by regulators requiring response action	Additional operational costs Financial loss small, <10%	Minimal effects on the natural environment	Minor effect on the broader economy due to disruption of service provided by the asset
Moderate	Some change in adaptive capacity. Renewal or repair may need new design to improve adaptive capacity	Limited infrastructure damage and loss of service Damage recoverable by maintenance and minor repair Early renewal of infrastructure by 20–50%	Frequent disruptions to employees, customers or neighbours. Adverse human health effects	Investigation by regulators Changes to management actions required	Moderate financial loss 10–50%	Some damage to the environment, including local ecosystems. Some remedial action may be required	High impact on the local economy, with some effect on the wider economy

Major	Major loss in adaptive capacity. Renewal or repair would need new design to improve adaptive capacity	Extensive infrastructure damage requiring major repair Major loss of infrastructure service Early renewal of infrastructure by 50–90%	Permanent physical injuries and fatalities may occur Severe disruptions to employees, customers or neighbours	Notices issued by regulators for corrective actions Changes required in management. Senior management responsibility questionable	Major financial loss 50–90%	Significant effect on the environment and local ecosystems. Remedial action likely to be required	Serious effect on the local economy spreading to the wider economy
Catastrophic	Capacity destroyed, redesign required when repairing or renewing asset	Significant permanent damage and/or complete loss of the infrastructure and the infrastructure service Loss of infrastructure support and translocation of service to other sites Early renewal of infrastructure by >90%	Severe adverse human health effects, leading to multiple events of total disability or fatalities Total disruptions to employees, customers or neighbours Emergency response at a major level	Major policy shifts Change to legislative requirements Full change of management control	Extreme financial loss >90%	Very significant loss to the environment. May include localized loss of species, habitats or ecosystems Extensive remedial action essential to prevent further degradation. Restoration likely to be required	Major effect on the local, regional and state economies

NOTES:

1 Adaptive capacity relates to the ability of the infrastructure element and/or organization to adapt/change/cope with change in the climate change variable.

2 Financial loss will be relative to the infrastructure element being considered (i.e. a single building, coastal town, rail system). Dollar values need to include replacement cost for the infrastructure item and financial loss/costs relating to the loss of the service provided by the infrastructure item.

3 While the term 'environment' can include both man-made and natural systems, in this Standard 'environment' is limited to the natural environment outside the asset being considered.

4 Economy refers to the local economy (e.g. town or region), the state economy, or the economy of Australia as a whole. Significance of this measure will depend on the asset

Table 5 - Risk rating matrix (Source: AS5334-2013).

Likelihood	Consequences				
	Insignificant	**Minor**	**Moderate**	**Major**	**Catastrophic**
Almost certain	L	M	H	E	E
Likely	L	M	M	H	E
Moderate	L	L	M	H	E
Unlikely	L	L	M	M	H
Very unlikely	L	L	L	M	M

LEGEND:
E = Extreme risk, requiring immediate action.
H = High risk issue requiring detailed research and planning at senior management level.
M = Moderate risk issue requiring change to design standards and maintenance of assets.
L = Low risk issue requiring action through routine maintenance of assets.

3.2.3 Decide what is an acceptable level of service

Decisions about when to adapt to a climate impact may be influenced by the need to maintain a certain level of service (whether that be the number of days per year that a road is open, the number of minutes a bus service is delayed, or a specified ambient temperature for office accommodation). It may make more economic sense to defer investing in an adaptation measure until a certain level of service threshold is reached.

Document any assumptions/ decisions about level of service in the risk assessment.

3.2.4 Note: Climate change impacts on flood risk

Australian Rainfall & Runoff is used by staff and contractors to specify appropriate stormwater infrastructure systems. In 2019 this was revised to take into account the effects of climate change. The six-step process provided in Book 1, Chapter 6 of Australian Rainfall & Runoff (Engineers Australia, 2014) should be used to factor climate change into stormwater design. Temperature projections contained in Appendix 4 should be used when calculating projected increases in rainfall intensity.

CASE STUDY: TORRENS TO TORRENS PROJECT

To assess the likely impacts of climate change on groundwater levels in the vicinity of the depressed road, the Torrens to Torrens project team used models to convert rainfall information into estimates of the depth to groundwater at the project site. Using the climate data produced by Goyder Institute for low-medium and high emissions scenarios, the project team then compared historical depth to groundwater with projected changes in depth to groundwater for the period 2015 to 2090. They found that groundwater levels are projected to decline due to rainfall changes in all future climate scenarios considered. Further information is provided in Appendix 8.

4 Assessment Step 3: Treatment options prioritisation

As in step 2, the prioritisation of treatment options must be undertaken by a multi-disciplinary team that has a deep understanding of the asset or program being assessed, and may include (where relevant):

- Risk managers
- Designers (e.g. with backgrounds in flooding, civil and structural design)
- Asset operators and maintenance staff
- Environmental and sustainability staff
- Community relations staff where relevant

The project or asset management team must ensure that treatment actions are identified and implemented (or planned) for all high and extreme priority risks identified in Step 2 above.

4.1 Identify potential treatment options

Potential strategies should be considered to eliminate or mitigate all extreme and high priority risks identified through assessment step 2. This may require desktop research, consultation with external specialists (e.g. suppliers of new products) or other departmental staff (e.g. staff who may have experience in dealing with similar climatic conditions in other parts of the State), or stakeholder engagement. Table 6 and 7 provide some guidance in how to think of treatment options.

Note that it is important not to consider the program or asset in isolation. Many departmental assets form part of a wider network which may be managed by other organisations. For example, it would be foolish to construct an elevated road in an area vulnerable to sea level rise without first investigating how the local council plans to address the broader flooding issue. There may be no need to elevate the road if the council plans to construct a levee which would provide adequate flood immunity. See section 3.1.4 'Understanding the Regional Context'.

Table 6 - Ways of adapting to climate change (Source: Main Roads WA Climate change risk assessment guideline)

Adaptation Treatment	Description	Expected Financial Implication	Example
Build for end of design life scenario	Build to maintain standards and level of service for the climate change scenario expected at end of life	Potentially higher upfront Costs, although no further costs for adaptation are required. Provides a higher level of service for entire design life. Risk that observed climate change will exceed projections.	Culvert is designed and constructed with capacity for identified climate change risks.
Planned adaptation	Plan an upgrade program to progressively adapt the infrastructure as climate change occurs. Initial design considers predicted climate changes and provides functionality to adapt the infrastructure at another time. Consultation with program and asset managers required to secure investment program.	Moderate upfront costs expected, although further investment is required during infrastructure life cycle. Provides some increase in level of service.	Culvert is designed and constructed for mid-life span climate change conditions but considerations made in current design for an upgrade in capacity i.e. second culvert can be installed in parallel.

Adaptation Treatment	Description	Expected Financial Implication	Example
Progressive Modification (existing asset)	Redesign and reconstruct as required and as possible in response to verified climate change as part of existing maintenance regime or project upgrades. Future verified climate changes will be captured in investigatory criteria of audits.	Moderate upfront costs expected. Further climate changes will force re-design. Higher costs to adapt asset in long term. Maintains level of service.	Culvert is constructed according to current climatic conditions (assume standards may not be current). Culvert will be upgraded if needed in future.
No Adaptation / Redundancy	No adaptation or making the overall asset redundant as there are suitable alternatives or the asset is not required	No extra investment required.	Culvert is not constructed at all or not replaced when it fails.

Table 7 - Types and examples of treatment options (Source: UKCIP 2007)

Types of treatment options	Examples
No-regrets – options that are worthwhile, justified (cost-effective).	- Avoiding building in high-risk areas e.g. flood plains for new development or when re-locating. - Conducting more frequent site inspections of infrastructure assets during extreme weather events. - Moving equipment and/or production elements to areas of lower risk. e.g. moving back up generators to areas less prone to flooding. - Developing new or update existing and internal standards/codes/guidelines to better consider climate change in infrastructure design e.g. changing the specification for purchase of air conditioners in the department's plant fleet from 45°C to 50°C. - Avoiding measures that may make it more difficult to adapt to a changing climate i.e. design decisions should not inadvertently increase climate vulnerability over time.
Low-regrets – options with relatively lost costs and large benefits.	- Restricting the type and extent of development in high-risk areas e.g. flood plains. - Adjusting the rainfall capacity of drainage infrastructure to withstand more rainfall without failure/flooding. - Including infrastructure protection measures into design e.g. sea walls to protect coastal infrastructure that cannot be located in less vulnerable areas. - Incorporating redundancy in design to allow continued operations despite the loss of some elements of the service or network. - Transferring the risk to third parties e.g. insurance parties where the risk is insurable.
Win-win - options that have the desired result of minimising risk but also deliver social, environmental and economic benefits.	- Improving preparedness and contingency planning to treat risk e.g. setting up early warning systems or signage in flood, bushfire and heatwave events. - Building community capacity of risks e.g. education and awareness campaign around public transport services during heatwave events. - Selecting more resilient materials and construction methods to make designs more robust in the face of increasing climate-related risk e.g. replacing timber sleepers with concrete sleepers. - Designing critical components of a system to cope with increased potential system failure due to extreme events.
Flexible treatment options – staging or delaying the implementation of options particularly if risks alter over various time periods (e.g. short, medium or long term).	- Progressively withdraw affected assets in coastal areas. - Time introduction of treatment options to coincide with planned maintenance and/or upgrading. - Building in a manner that allows retrofitting at a later date when climate change impacts may occur e.g. allow width of a road corridor to raise for flooding at later date.

Types of treatment options	Examples
	- Designing for future climatic conditions if the asset is expected to operate for the next 50 years. Alternatively, decrease the expected asset life to 10 years and only consider current climate conditions. In some cases, shorter design life may offer greater flexibility to help manage uncertainty.

4.1 Re-assess residual risk

For high priority risks that require mitigation, repeat steps (a), (b) and (c) in Section 3.2.2 for each treatment option identified. Risk treatments should aim to reduce either the likelihood or consequence of the risk, and

Following treatment, there should be no Extreme or High Priority residual risks.

4.2 Evaluate the treatment options

Once the risk treatment options have been identified deemed to effectively manage risks, assess and prioritise them using the project team or business unit's preferred decision making tool (e.g. Benefit Cost Analysis or Multi-Criteria Analysis).

Options assessment must consider environmental, social and economic aspects and must be based on whole-of-life impacts. An example of the evaluation criteria and ratings that might be used in an MCA is shown in Table 3 and 4.

Table 3. Example of multi criteria assessment of treatment options (Source: AS5334-2013).

Risk	Treatment option	Economic efficiency										Consequences of actions/inaction					
		Effectiveness	Cost	Funding options	Time to implement	Duration	Technical feasibility	Human capability	Regulatory impact	Community acceptance	Benefit	Climate change impact	Social impact	Environmental impact	Co-benefits	Secondary risks	Residual risk
1	**A**																
	B																
	C																
2	**A**																
	B																
	C																
3	**A**																
	B																

Table 4. Example of evaluation criteria for MCA.

Criteria	Highly Unfavourable (1)	Unfavourable (2)	Moderately Favourable (3)	Highly Favourable (4)
Cost (AUD$)	100,000,000+ Major costs	10,000,000-100,000,000 High costs	1,000,000-10,000,000 Medium costs	<1,000,000 Low costs
Effectiveness	Potential to reduce risk is uncertain	Potential to reduce risk is low	Moderate potential to reduce risk	High potential to reduce risk
Timeliness	Implementation best delayed for at least 10 years	Initial implementation likely to be greater than 5 years	Initial implementation possible between 2-5 years	Initial implementation possible within 2 years
Environmental, financial and social impacts	Highly negative	Moderately negative	Moderately positive	Highly positive

Note that issues of timing will play a part in the urgency of response. For example, extreme risks manifesting in 2070 may not require immediate response, but treatment options should be identified and recorded so that they can be communicated to the asset manager.

Some adaptation measures may only be necessary if a certain threshold is reached within the expected design life/ program timeframe. Figure 2 below shows how adaptation actions might be staged so as to avoid significant upfront capital expenditure on infrastructure that is ‘overdesigned’ for the immediate risk.

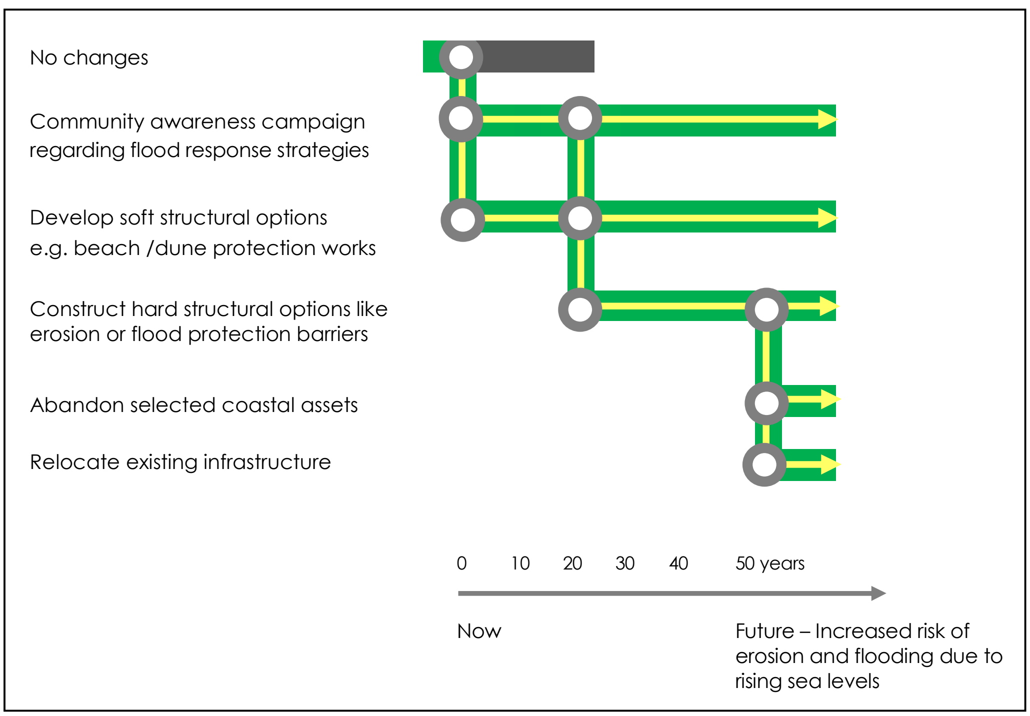


Figure 2 Example of staged adaptation to address the issue of managing coastal assets in the face of rising sea levels. Not all actions need to be taken immediately.

Adapted from Regional Climate Change Adaptation Plan for the Eyre Peninsula (2014)

The Roads and Maritime Services NSW Pacific Highway upgrade offers a good example of staged adaptation (see boxed text below, and Appendix 6). This approach was also taken for the Kempsey-Frederickton Bypass (Appendix 5).

The case studies below illustrate the strategic implementation of adaptation actions through a staged process.

CASE STUDY: PACIFIC HIGHWAY UPGRADE

NSW Roads and Maritime Services took a staged adaptation approach to the Pacific Highway upgrade (Woolgoola to Ballina). Whilst it was predicted that the road embankments will need to be raised by up to 0.2m to protect against future sea level rise, RMS decided to defer this investment, recognising that road pavements require periodic rehabilitation every 30-40 years and this could include raising the pavement by 0.2m without substantial changes to the road design. This meant that the capital expenditure required to adapt to future climate change would be outlaid closer to the required time. RMS did, however, widen the project boundary by up to 1.6m in places to accommodate future increases in embankment height (allowing for a batter slope of 1:4). See the summary in **Appendix 6** (knet #9273619).

CASE STUDY: IMPACT OF TEMPERATURE ON SPRAYED SEAL

Main Roads WA assessed the impact of projected temperature increases on the life expectancy of sprayed seals for 2030, 2050, 2070 and 2100. The assessment showed a potential reduction in seal life of 1 to 2 years within the next 20 years, and up to 5 years by the end of the century (when compared to current reseal frequency). Whilst no immediate action is required, adjustments in seal/ reseal frequency can be planned for in future. See **Appendix 7** for further information.

CASE STUDY: WEST LAKES TIDAL FLUSHING SYSTEM

The Department manages the West Lakes flushing system to ensure water quality standards are maintained in the lake. An initial assessment of the impacts of sea level rise on West Lakes tidal flushing system (**Appendix** 7) assessed the impact at 2050 and 2100 to determine when the frequency of flushing using the current natural tidal flow process is likely to fall below acceptable levels and thus when it will be necessary to implement a mechanical pumping system.

CASE STUDY: SALTFLEET STREET BRIDGE

The approaches to Saltfleet Street bridge currently flood during the combination of spring tide and storm surge, which happens once every couple of years. However, by 2100, this can be expected to occur approximately once a month due to sea level rise. The current level of service for this road (i.e. temporary loss of access once every couple of years) is considered acceptable, and the department is not planning to raise the height of the road. However, the level of service in 2100 (loss of access once a month) is unlikely to be acceptable. A decision will need to be made regarding the desired level of flood immunity / level of service, which will determine when to raise the approaches to Saltfleet Street Bridge.

5 Step 4: Risk documentation and review

5.1 Document the risks and preferred treatment options

Document how each treatment option addresses the relevant risk(s), and what the implications are for level of service (if applicable).

Summarise the outcomes of Step 4.2, outlining what is the preferred treatment option and why. An example is provided in Appendix 5 – *Project Response to Climate Change Considerations for the Kempsey-Frederickton Bypass*.

Where risks are not addressed, provide rationale supporting this decision for transparency.

Ensure risks are integrated into relevant risk registers for tracking. For example, organisational climate risks should be integrated into the broader departmental risk management register; project level risks should be included in the project's risk register.

If the project's response is to defer adaptation action until a future date, it will be important to incorporate the required action(s) into asset management plans and forward planning/ budgeting frameworks.

5.2 Assign responsibility

For risks that require further or ongoing management, assign responsibility to a relevant staff member. The person responsible must be the relevant discipline lead that has the ability to action, implement or plan treatment measures for priority risks. Responsibility may also involve partnerships and/or engagement with external parties.

References and Further Information

This section provides a list of further references and information for staff using this guide.

Step 1: Screening

Austroads, *2004, Impact of Climate Change on Road Infrastructure* (publication no: AP–R243/04), available from https://www.onlinepublications.austroads.com.au/items/AP-R234-04

Intergovernmental Panel on Climate Change (IPCC), 2014, various reports available from http://www.ipcc.ch/report/ar5/

ISCA, 2018, *IS V2.0 Design and As Built Technical Manual,* Infrastructure Sustainability Council of Australia, Sydney

Step 2: Climate risk analysis

Engineers Australia, 2014, *Australian Rainfall and Runoff Discussion Paper: An interim guideline for considering climate change in rainfall and runoff*, accessed 13 February 2015, http://www.arr.org.au/wp-content/uploads/2013/Projects/Draft_ARR_interim_guidance_Format.pdf

CSIRO, 2007, *Climate Change in Australia – Technical Report*, accessed 24 June 2014, http://www.csiro.au/Organisation-Structure/Divisions/Marine--Atmospheric-Research/Climate-Change-Technical-Report-2007.aspx

Department of the Environment, 2008, *The Garnaut Climate Change Review*, available from http://www.garnautreview.org.au/

Department of the Environment, 2009, *Climate Change Risks to Australia's Coasts – A First Pass National Assessment*, accessed 24 June 2014, http://www.environment.gov.au/climate-change/adaptation/publications/climate-change-risks-australias-coasts

Department of the Environment, *Climate change impacts in Australia*, available from http://www.climatechange.gov.au/climate-change/climate-science/climate-change-impacts-australia

Department of Environment and Heritage, (2006), *Climate Change Impacts & Risk Management – A Guide for Business and Government*, accessed 24 June 2014, http://www.environment.gov.au/climate-change/adaptation/publications/climate-change-impact-risk-management

Department of Planning, Transport and Infrastructure (DPTI), 2015, *Risk Management Policy* (Policy No. DP086)

Office of Environment and Heritage NSW (2011) Guide to climate change risk assessment for NSW local government http://climatechange.environment.nsw.gov.au/Adapting-to-climate-change/Local-government/Adaptation-planning

Standards Australia, 2009, *AS/NZS ISO 31000:2009 Risk Management – Principles and guidelines*, Standards Australia, Sydney

Standards Australia, 2013, *AS 5334-2013 Climate change adaptation for settlements and infrastructure - A risk based approach*, Standards Australia, Sydney.

Current Climate Data

The following links from the Bureau of Meteorology (BoM) allow you to view current climate observations:

- Bureau of Meteorology: current climate data for South Australia> http://www.bom.gov.au/sa/observations/index.shtml
- Bureau of Meteorology: current climate data for Adelaide> http://www.bom.gov.au/sa/observations/adelaidemap.shtml
- Bureau of Meteorology: current climate data for individual sites> http://www.bom.gov.au/climate/change/hqsites/
- Bureau of Meteorology: current climate data for individual weather stations > http://www.bom.gov.au/climate/data/

Future Climate Data

The most recent South Australian guidelines for climate change data are provided in the Guide to Climate Projections for Risk Assessment and Planning in South Australia developed by Green, G and Pannell, A in 2020 for the Department for Environment and Water. This guidance document contains detailed projections from both the Goyder Institute as well as CSIRO Climate Change in Australia, summarised below.

The regional climate projection tables in Appendix 4 for South Australia are based on projections for 2030 and 2070 by the Goyder Institute for Water Research (2015) Statistically Downscaled Climate Change Projections for South Australia and South Australian Research and Development Institute (SARDI) > https://www.sa.gov.au/topics/water-energy-and-environment/climate-change/climate-change-in-south-australia/regional-climate-change-projections

The CSIRO Climate Change in Australia website (http://www.climatechangeinaustralia.gov.au/en/climate-projections/explore-data/about-data/) allows you to access projected climate conditions for specified scenarios and timeframes, including extreme rainfall and temperature. It also allows you to look at projected changes in number of days above or below selected thresholds for maximum and minimum temperature. Free registration is required to access some data.

Antarctic Climate and Ecosystems Cooperative Research Centre's Canute Sea Level Calculator > http://canute2.sealevelrise.info/

Step 3: Identify and prioritise treatment options

Department of the Environment, 2007, *National Climate Change Adaptation Framework*, http://www.environment.gov.au/climate-change/adaptation/adaptation-framework

Department of the Environment, 2010, *Adapting to Climate Change in Australia*, http://www.climatechange.gov.au/climate-change/publications/adapting-climate-change-australia%E2%80%94-australian-government-position-paper

Engineers Australia (2013) *Guidelines for Responding to the Effects of Climate Change in Coastal and Ocean Engineering*

http://www.engineersaustralia.org.au/sites/default/files/shado/Learned%20Groups/National%20Committees%20and%20Panels/Coastal%20and%20Ocean%20Engineering/vol_1_web.pdf

Local Government of South Australia, 2012, *Guidelines for development a climate change adaptation plan and undertaking an integrated climate change vulnerability assessment*, http://www.lga.sa.gov.au/webdata/resources/files/Guidelines_for_Developing_a_Climate_Change_Adaptation_Plan.pdf

Department of Environment, Water and Natural Resources, South Australia 2012, *Prospering in a changing climate*, https://www.sa.gov.au/__data/assets/pdf_file/0011/10901/CC_framework_2012_web_V3.pdf

NZ Transport Agency (2009) *Climate change effects on the land transport network Volume 2: Approach to risk management. NZ Transport Agency Research Report 378* *http://www.nzta.govt.nz/resources/research/reports/378/docs/378-v2.pdf*

UKCIP (2007). Identifying adaptation options. https://ukcip.ouce.ox.ac.uk/wp-content/PDFs/ID_Adapt_options.pdf

UKCIP. *Adaptation Wizard and case studies*, http://www.ukcip.org.uk/wizard/

Case Studies

Department of the Environment, 2011, *Adaptation of Melbourne's Metropolitan Rail Network in Response to Climate Change*, accessed 24 June 2014 http://www.environment.gov.au/climate-change/adaptation/publications/adaptation-melbournes-metropolitan-rail-network-response-climate-change

Department of the Environment, 2011, *Coastal inundation at Narrabeen Lagoon – Optimising adaptation investment*, accessed 24 June 2014, http://www.environment.gov.au/climate-change/adaptation/publications/coastal-inundation-narrabeen-lagoon-optimising-adaptation-investment

Department of the Environment, 2012, *Securing long-term water supply in a time of climatic uncertainty – Prioritising adaptation investment*, accessed 24 June 014, http://www.environment.gov.au/climate-change/adaptation/publications/securing-water-supply

Climate Adaptation Plans

Balston, J.M., Billington, K., Cowan, H., Hayman, P., Kosturjak, A., Milne, T., Rebbeck, M., Roughan, S., Townsend, M. (2011). *Central local government region integrated climate change vulnerability assessment. Central Local Government Region of South Australia, Crystal Brook, SA.*

Siebentritt, M., Halsey, N. and Stafford-Smith, M. (2014) *Regional Climate Change Adaptation Plan for the Eyre Peninsula*. Prepared for the Eyre Peninsula Integrated Climate Change Agreement Committee.

Glossary

Adaptation	The process of adjustment to actual or expected climate and its effects. Referred to as 'risk treatment' throughout this document.
Adaptive capacity	The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.
Climate projection	A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases (GHGs), generally derived using climate models.
Climate scenario / **Emission scenario**	A plausible and often simplified representation of the future climate, based on an internally consistent set of assumptions and climatological relationships (such as technological change, demographic and socioeconomic development) that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change. Concentration scenarios, derived from emission scenarios, are used as input into climate models to estimate potential changes in climate. In the IPCC's 5AR, climate scenarios are now called 'Representative Concentration Pathways' (RCPs). Four RCPs have been used by IPCC to project future climate. The trend over past 10 years in greenhouse gas emissions and global warming is tracking in line with a high emissions scenario. It is recommended that a high emissions scenario is selected. The equivalent RCP for this scenario is RCP8.5.
Cost–benefit analysis (CBA)	Cost-benefit analysis is an economic decision support tool that can be used to determine in monetary terms whether the total benefits of a treatment option exceed its total costs. This involves calculating monetary values for all expected costs and benefits for the proposed option. This may include direct costs and benefits to the organisation as well as those external to the organisation.
Exposure	Degree of climate stress; may be represented as either gradual or long term changes in climate conditions. There are two main element to consider in exposure: - That which can be affected by climate change. - The change in climate itself.
Representative Concentration Pathways (RCPs)	Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/land cover (Moss et al., 2008). Four RCPs produced from Integrated Assessment Models were selected from the published literature and are used in the present IPCC Assessment as a basis for the climate predictions and projections presented in WGI AR5 Chapters 11 to 14: - RCP2.6 One pathway where radiative forcing peaks at approximately 3 W m^{-2} before 2100 and then declines (the corresponding ECP assuming constant emissions after 2100); - RCP4.5 and RCP6.0 Two intermediate stabilization pathways in which radiative forcing is stabilized at approximately 4.5 W m^{-2} and 6.0 W m^{-2} after 2100 (the corresponding ECPs assuming constant concentrations after 2150); - RCP8.5 One high pathway for which radiative forcing reaches greater than 8.5 W m^{-2} by 2100 and continues to rise for some amount of time (the corresponding ECP assuming constant emissions after 2100 and constant concentrations after 2250).
Resilience	According to the IS Technical Manual V2.0 (2018), resilience refers to "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions".
Sensitivity	Degree to which a system will be affected by or in response to climate.
Shocks	In the context of civil infrastructure climate resilience, shocks refer to high impact, one-off events such as natural disasters, including floods, severe storms, bushfires and extreme heat days.
Stresses	In the context of civil infrastructure climate resilience, stresses are defined as chronic climate issues that occur over a long period. These may include increased average temperatures and longer dry periods which may lead to more rapid degradation of assets and subsequent increased vulnerability to shocks.

Appendix 1: Climate Change Risk Assessment Reporting template

CLIMATE CHANGE ASSESSMENT FOR [NAME OF PROJECT]

Prepared by [Name person/ section/ division]

Date prepared:

Note: The guidance needed to complete a climate change planning assessment is found in the DITI Climate Change Adaptation Guideline (knet 16554163). Use of the template is optional. It is designed to help document the outcomes of the assessment, but information should be incorporated into key project documents (eg Business Case, Environmental Impact Assessment Report or Planning Impact Report).

1.0 Executive Summary

Describe the project/ activity. Include details on design life/ asset life/ planning horizon, and description of regional context.

2.0 Climate Change Assessment

In accordance with the department's Climate Change Adaptation Strategy, an assessment of potential climate change impacts has been undertaken using the department's Climate Change Adaptation Guideline. The following climate change projections are considered to present a risk to the project:

- increases in extreme temperature
- …add more as necessary

This section discusses how risks have been assessed and how they will be managed.

2.1 Projections

State the assumed design life/ planning horizon, and hence which climate projections were considered, ie 2030, 2050, 2070 etc. Long term assets (with lifetimes beyond 2050) must employ both RCP 4.5 and RCP 8.5 projections.

State the source of the projections or any other guidance material used, eg CSIRO Climate futures website, Goyder Institute, Australian Rainfall & Runoff interim climate change guidelines, Coast Protection Board requirements etc

Summarise the projection scenarios employed and their characteristics for the region.

2.2 Impacts

2.2.1 Projected increase in extreme temperature

Describe how the asset/ activity/ level of service is currently impacted by extreme temperatures – what happens, how often does it happen, how does it affect level of service, what are the flow-on effects, what controls are in place, etc.

Based on current knowledge, describe the likely impact of an increase in the frequency of hot and very hot days at relevant timeframes (eg 2030, 2050 etc). Are the current controls likely to be adequate/ sustainable? Will it be possible to maintain the desired level of service?

Describe the context – will external factors influence the impact?

2.2.1 Repeat this for other climate variables, as necessary

2.3 Treatment options

2.3.1 Projected increase in extreme temperature

Discuss what mitigation options are available (including Do Nothing). Describe how the various treatment options have been evaluated.

Which is the preferred option and why? If the decision is to not treat the risk, explain why. Include details of risk ratings (from likelihood and consequence tables) and acceptance levels.

If relevant, describe how the preferred strategy complements or impacts on any other work being undertaken by other organisations.

2.3.2 Repeat this for other climate variables, as necessary

2.4 Proposed management strategy

2.4.1 Projected increase in extreme temperature

Summarise the proposed strategy and timing of the strategy

Discuss any changes that may be required to current asset/ program management practices/ policies etc

Document who is responsible for implementing the strategy

2.4.2 Repeat this for other climate variables, as necessary

3.0 Future/ ongoing tasks

The risks identified through this assessment have been recorded in [business risk register/ database/ asset management plan/ project report] and should be reviewed [insert year/ timeframe for review].

Describe any future tasks that need to take place as part of the risk management strategy, eg changes to asset/program management practices/ policies and how these are being progressed. If it has been decided to defer adaptation, specify when it is planned to implement adaptation measures and confirm that either the asset management plan has been updated to reflect this, or drawings/ requirements have been filed for future use.

If further research/ investigations are required, discuss how this will be delivered (eg who will coordinate budget bids for research work/ trials etc

Appendix 2: Climate Change Risk Assessment Checklist

Assessment stage	Key question	Response								Reference
Step 1: Screening	Has screening for direct climate sensitivities been undertaken?	☐	**Yes**			☐	**No**			
	Were any climate sensitivities identified?	☐	**Yes**			☐	**No**			
Step 2: Climate Risk Analysis	Was a multi-disciplinary group involved in identifying risks?	☐	**Yes**			☐	**No**			
	Were asset or program operational objectives defined?	☐	**Yes**			☐	**No**			
	What is the asset / program design life?					**Years**				
		Short term				**Long term**				
	Which climate projection timeframes were employed?									
	Which scenarios were employed (e.g. RCP 4.5, RCP 8.5)									
	Was a current and future climate context developed?	☐	**Yes**			☐	**No**			
	Was the regional context reviewed?	☐	**Yes**			☐	**No**			
	Outline the number of risks identified:		**Low**		**Mod.**		**High**		**Extreme**	
Step 3: Risk treatment	Was a multi-disciplinary group involved in identifying treatment actions?	☐	**Yes**			☐	**No**			
	Have treatment options been identified for priority risks?	☐	**Yes**			☐	**No**			
	After treatment, are there any high or extreme residual risks?	☐	**Yes**			☐	**No**			
Step 4: Documentation and review	Have risks and treatment options been appropriately documented?	☐	**Yes**			☐	**No**			
	Have risks been incorporated into the relevant project or asset management risk register?	☐	**Yes**			☐	**No**			
	Has responsibility been assigned to priority risks and treatment actions	☐	Yes			☐	No			

Appendix 3: Potential vulnerabilities of key asset elements

The table below (adapted from IPWEA 2018) provides guidance to assess the vulnerability level of key elements within buildings, roads and bridges to different climate change impacts. It also provides typical useful life of the asset elements to assist on the assessment. Colour coding indicates the potential vulnerability of each asset element and whether the potential for a reduction in the useful life of the asset. Low vulnerability of the asset element is marked in green, Medium vulnerability in yellow and medium to large vulnerability is marked in red. Note: (1) The useful life of landscaping depends on the types of vegetation planted, which can range from short lifespan shrubs and groundcovers of up to 10 years through to trees that can survive for at least 100 years depending on local conditions. (2) Car parks are listed with buildings. These relate specifically to ground level car parks surrounding buildings and do not relate to multi-storey car parks, which would have multiple asset elements in their own right.

Asset element	Useful life (y)	Climate impact									
		Increase in intensity of hot days	Increased average temperatures	Increase in frequency of very hot days	Increased bushfire weather	Increased duration of heatwaves	More frequent/ severe droughts	Increased extreme rainfall intensity / flooding	Increased intensity of hailstorms	Increased intensity of extreme winds	Increased sea level rise and storm surge
Buildings											
Concrete retaining walls	75	Medium	Medium	Medium	Medium	Medium	Medium	High	Low	Low	Medium
Timber retaining walls	60	Low	Low	Low	High	Low	Low	High	Low	Low	High
External walls- Brick cladding	75	Medium	Medium	Medium	High	Medium	Medium	Medium	Low	Medium	Medium
External walls -PVC weatherboards	35	Medium	Medium	Medium	High	Medium	Medium	High	High	Medium	Low
External walls- Timber weatherboards	75	Medium	Medium	Medium	High	Medium	Low	High	High	Medium	Medium
Curtain walling (glass)	60	Medium	Medium	Medium	High	Medium	Low	High	High	Medium	Medium
Signs	10	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
Metal roofs	30	Low	Low	High	High	High	Low	Low	High	Medium	Low

Asset element	Useful life (y)	Climate impact									
		Increase in intensity of hot days	Increased average temperatures	Increase in frequency of very hot days	Increased bushfire weather	Increased duration of heatwaves	More frequent/ severe droughts	Increased extreme rainfall intensity / flooding	Increased intensity of hailstorms	Increased intensity of extreme winds	Increased sea level rise and storm surge
Tile roofs (clay)	65	Low	Low	Low	Medium	Low	medium	Low	High		Low
Tile roofs (concrete)	100	Low	Low	Low	Medium	Low	Low	Low	High	Medium	Low
Mechanical services (split air conditioning systems)	9	Low	Low	Low	Low	Low	Low	Low	High	Low	Low
Roof downpipes (Metal)	35	Low	Low	Low	High	Low	Low	Medium	High	Medium	Low
Roof downpipes (PVC)	33	Low	Low	Low	High	Low	Medium	Medium	High	Medium	Low
Paved footpath	46	Low	Low	Low	Medium	Low	Medium	High	Low	Low	High
Concrete footpath	54	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Low	Low	Medium
Windows	55	Low	Low	Low	High	Low	Low	Medium	High	High	Medium
Car parks (ground level)	20	Medium	Medium	Medium	High	Medium	Low	High	Low	Low	High
Landscaping	10-100	High	High	High	High	High	High	Medium	Medium	Medium	Low
Roads											
Surfaces in urban areas (spray seal)	22	Medium	Medium	Medium	High	Medium	Low	High	Low	Low	High
Surfaces in urban areas (cold overlay)	17	Medium	Medium	Medium	High	Medium	Low	High	Low	Low	High
Surfaces in urban areas (hotmix)	26	Medium	Medium	Medium	High	Medium	Low	High	Low	Low	High

Asset element	Useful life (y)	Climate impact									
		Increase in intensity of hot days	Increased average temperatures	Increase in frequency of very hot days	Increased bushfire weather	Increased duration of heatwaves	More frequent/ severe droughts	Increased extreme rainfall intensity / flooding	Increased intensity of hailstorms	Increased intensity of extreme winds	Increased sea level rise and storm surge
Surfaces in rural areas (spray seal)	21	Medium	Medium	Medium	High	Medium	Low	High	Low	Low	High
Surfaces in rural areas (cold overlay)	20	Medium	Medium	Medium	High	Medium	Low	High	Low	Low	High
Surfaces in rural areas (hotmix)	24	Medium	Medium	Medium	High	Medium	Low	High	Low	Low	High
Urban granular pavement- unsealed	83	Low	Low	Low	Low	Low	Low	High	High	Low	High
Rural granular pavement- unsealed	68	Low	Low	Low	Low	Low	Low	High	High	Low	High
Signaling	20	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
Drainage basins	98	Medium	Medium	Medium	Medium	Medium	Medium	High	High	Low	Medium
Storm water assets- reinforced concrete pipes	98	Medium	Medium	Medium	Medium	Medium	Medium	Medium	High	Low	Medium
Stormwater assets- uPVC	97	Low	Low	Low	Medium	Low	Low	Medium	High	Low	Medium
Bridges											
Steel beams	87	Low	Low	Low	Medium	Low	Low	High	Low	High	High
Timber beams	59	Low	Low	Low	High	Low	Low	High	Low	Low	Medium
Concrete beams	83	Low	Low	Low	Medium	Low	Medium	Medium	Low	Low	Medium
Abutment stone	80	Low	Low	Low	Low	Low	low	High	Low	Low	Medium

Asset element	Useful life (y)	Climate impact									
		Increase in intensity of hot days	Increased average temperatures	Increase in frequency of very hot days	Increased bushfire weather	Increased duration of heatwaves	More frequent/ severe droughts	Increased extreme rainfall intensity / flooding	Increased intensity of hailstorms	Increased intensity of extreme winds	Increased sea level rise and storm surge
Abutment concrete	85	Low	Low	Low	Medium	Low	Medium	High	Low	Low	low
Metal barriers and handrails	70	Low	Low	Low	Medium	Low	Low	High	Low	Low	Medium
Timber barriers	60	Low	Low	Low	High	Low	Low	High	Low	Low	High
Concrete barriers	80	Low	Low	Low	Medium	Low	Medium	High	Low	Low	Medium
Timber surface	57	Medium	Medium	Medium	High	Medium	Low	High	High	Low	Medium
Concrete or culvert surface	86	Medium	Medium	Medium	Medium	Medium	Low	High	High	Low	Medium

Appendix 4: South Australian Climate Data Maps and Tables

The tables in the following pages are a summary of climate projections for South Australia's natural resource management (NRM) regions, based on RCP8.5. The projections are taken from the *Guide to Climate Projections for Risk Assessment and Planning in South Australia* (with the exception of runoff projections, discussed below). For more detailed summaries of regional projections, including those for RCP 4.5, refer directly to the Guide.

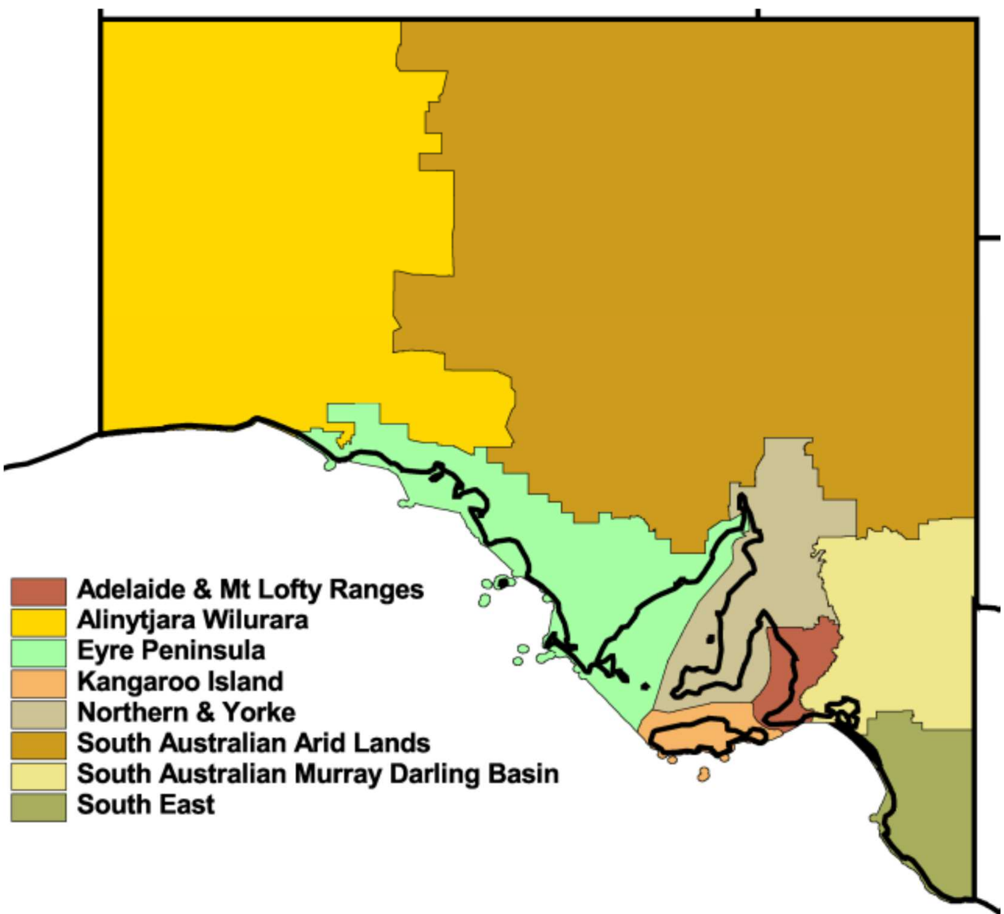
Runoff projections are based on:

Chiew, F.H., and T. A. McMahon 2002, 'Modelling the impacts of climate change on Australian streamflow', *Hydrological Processes*, vol. 16, pp. 1235–1245

This research suggests that reductions in runoff are proportionately greater than reductions in rainfall. A 10% decline in rainfall can equate to up to 25% reduction in stream flow or run off. If specific information is required for surface water runoff, refer to the Goyder climate projections which will provide detailed rainfall data for hydrological models. These can be found via the SA Climate Ready website (https://data.environment.sa.gov.au/Climate/SA-Climate-Ready/Pages/default.aspx) and in the technical report:

Charles SP, Fu G (2015) 'Statistically Downscaled Climate Change Projections for South Australia', Goyder Institute for Water Research Technical Report Series No. 15/1, Adelaide, South Australia.

NRM Region Boundaries:



Adelaide and Mount Lofty Ranges Climate Data (RCP8.5)

Variable	2030	2050	2070	2090
Average temperature (°C) (Annual daily maximum)	+1.1	+1.8	+2.6	+3.4
Average rainfall (%) (Annual)	-5.4	-8.4	-13.6	-17.4
Vapour pressure deficit (%) (Annual)	+10.8	Data not provided	+27.4	+37.1
Potential evaporation (%) (Annual)	+3.1	+5.2	+7.4	+9.9
Relative humidity (%) (Annual)	-0.3 (-0.1 to 0.4)	Data not provided	Data not provided	-1.6 (-3.2 to -0.3)
Solar radiation (%) (Annual)	1.2	Data not provided	2.4	3.2
Wind speed (%) (Annual)	-0.5 (-3.1 to 0.7)	Data not provided	Data not provided	-1.8 (-4.4 to 0)
Extreme temperature (Days over 35°C)	+5.2	+9.8	Data not provided	+20.3
Very high or extreme fire risk days	+0.5	Data not provided	Data not provided	+2.7
Change in runoff (%) (Mean annual runoff)	Reduction in mean annual runoff potentially two to three times greater than projected reduction in rainfall.			
Rainfall intensity (%)	5.5%	Data not provided	13%	17%
Storm surge	State Government Policy is to allow for 0.3m of sea level rise from 1990 to 2050 and 1.0m to 2100. The Coast Protection Board is able to advise on anticipated sea level rise at specific locations.			
Sea level rise	+0.13 (+0.08 - +0.17)	+0.25 (+0.16 - +0.33)	Data not provided	+0.61 (+0.40 - +0.84)

Eyre Peninsula Climate Data (RCP8.5)

Variable	2030	2050	2070	2090
Average temperature (°C) (Annual daily maximum)	+1	+1.7	+2.4	+3.3
Average rainfall (%) (Annual)	-7.5	-11.8	-16.1	-20.9
Vapour pressure deficit (%)(Annual)	+9.8	Data not provided	+23.4	+31.2
Potential evaporation (%) (Annual)	+2.7	+4.6	+6.7	+9.0
Relative humidity (%) (Annual)	-0.3 (-0.1 - 0.4)	Data not provided	Data not provided	-1.6 (-3.2 - -0.3)
Solar radiation (%) (Annual)	0.9	Data not provided	1.7	2.1
Wind speed (%) (Annual)	-0.5 (-3.1 - 0.7)	Data not provided	Data not provided	-1.8 (-4.4 – 0)
Extreme temperature (Days over 35°C)	+5.2	+9.8	Data not provided	+20.3
Very high or extreme fire risk days	+0.5	Data not provided	Data not provided	+2.7
Change in runoff (%) (Mean annual runoff)	Reduction in mean annual runoff potentially two to three times greater than projected reduction in rainfall.			
Rainfall intensity (%)	5%	Data not provided	11%	16.5%
Storm surge	State Government Policy is to allow for 0.3m of sea level rise from 1990 to 2050 and 1.0m to 2100. The Coast Protection Board is able to advise on anticipated sea level rise at specific locations.			
Sea level rise	+0.12 (+0.08 - +0.17)	Data not provided	Data not provided	+0.59 (0.39 - 0.82)

Kangaroo Island Climate Data (RCP8.5)

Variable	2030	2050	2070	2090
Average temperature (°C) (Annual daily maximum)	+0.8	1.4	+2.1	+2.8
Average rainfall (%) (Annual)	-5.9	-8.9	-14.8	-18.8
Vapour pressure deficit (%) (Annual)	+6.7	Data not provided	+18.1	+24.8
Potential evaporation (%) (Annual)	+2.4	+4.1	+6.2	+8.4
Relative humidity (%) (Annual)	-0.3 (-0.1- 0.4)	Data not provided	Data not provided	-1.6 -3.2 - -0.3
Solar radiation (%) (Annual)	+1	Data not provided	+2.1	+2.8
Wind speed (%) (Annual)	-0.5 (-3.1 - 0.7)	Data not provided	Data not provided	-1.8 (-4.4 – 0)
Extreme temperature (Days over 35°C)	+5 (+3 - +8)	Data not provided	Data not provided	+27 (+18 - +37)
Very high or extreme fire risk days	+0.5	Data not provided	Data not provided	+2.7
Change in runoff (%) (Mean annual runoff)	Reduction in mean annual runoff potentially two to three times greater than projected reduction in rainfall.			
Rainfall intensity (%)	4%	Data not provided	10%	14%
Storm surge	State Government Policy is to allow for 0.3m of sea level rise from 1990 to 2050 and 1.0m to 2100. The Coast Protection Board is able to advise on anticipated sea level rise at specific locations.			
Sea level rise	+0.13 (+0.08 to +0.17)	+0.24 (+0.16 to +0.33)	Data not provided	+0.60 (+0.39 to +0.83)

Northern and Yorke Climate Data (RCP8.5)

Variable	2030	2050	2070	2090
Average temperature (°C) (Annual daily maximum)	+1.2	1.9	+2.8	+3.7
Average rainfall (%) (Annual)	-9.4	-15	-20.9	-26.9
Vapour pressure deficit (%) (Annual)	+13	Data not provided	+31.2	+42
Potential evaporation (%) (Annual)	+3.4	+5.5	+7.9	+10.5
Relative humidity (%) (Annual)	-1 to 0.4 (-0.3)	Data not provided	No data provided	-3.2 to -0.3 (-1.6)
Solar radiation (%) (Annual)	+1.3	Data not provided	+2.2	+2.6
Wind speed (%) (Annual)	-0.5 (-3.1 to 0.7)	Data not provided	Data not provided	-4.4 to 0 (-1.8)
Extreme temperature (Days over 35°C)	+10.1	+19.5	Data not provided	+42
Very high or extreme fire risk days	+0.5	Data not provided	Data not provided	+2.7
Change in runoff (%) (Mean annual runoff)	Reduction in mean annual runoff potentially two to three times greater than projected reduction in rainfall.			
Rainfall intensity (%)	6%	Data not provided	14%	18.5%
Storm surge	State Government Policy is to allow for 0.3m of sea level rise from 1990 to 2050 and 1.0m to 2100. The Coast Protection Board is able to advise on anticipated sea level rise at specific locations.			
Sea level rise	+0.13 (+0.08 to +0.17)	+0.25 (+0.16 to +0.33)	Data not provided	+0.61 (+0.40 to +0.84)

South Australian Arid Lands Climate Data (RCP8.5)

Variable	2030	2050	2070	2090
Average temperature (°C) (Annual daily maximum)	+1.3	2.1	+3	+4
Average rainfall (%) (Annual)	-8.8	-10.6	-11.5	-17.9
Vapour pressure deficit (%) (Annual)	+11.2	Data not provided	+27.2	+36.6
Potential evaporation (%) (Annual)	+3.2	+5.2	+7.6	+10.2
Relative humidity (%) (Annual)	-1.8 to 0.8 (-0.8)	Data not provided	Data not provided	-5.1 to +0.4 (-2.6)
Solar radiation (%) (Annual)	+0.6	Data not provided	+0.8	+1
Wind speed (%) (Annual)	-0.1 (-1.2 to 1)	Data not provided	Data not provided	-2.4 to 2 (0.7)
Extreme temperature (Days over 35°C)	+12.7	+24.7	Data not provided	+50
Very high or extreme fire risk days	+5.6	Data not provided	Data not provided	+14.9
Change in runoff (%) (Mean annual runoff)	Reduction in mean annual runoff potentially two to three times greater than projected reduction in rainfall.			
Rainfall intensity (%)	6%	Data not provided	15%	20%
Storm surge	Not applicable.			
Sea level rise				

South Australian Murray-Darling Basin Climate Data (RCP8.5)

Variable	2030	2050	2070	2090
Average temperature (°C) (Annual daily maximum)	+1.1	+1.9	+2.7	+3.6
Average rainfall (%) (Annual)	-8.8	-12.8	-11.5	-21.7
Vapour pressure deficit (%) (Annual)	+12.1	Data not provided	+29.9	+40.3
Potential evaporation (%) (Annual)	+3.1	+ 5.3	+7.6	+10.2
Relative humidity (%) (Annual)	-1.6 to 0.5 (-0.7)	Data not provided	Data not provided	-5.8 to -0.8 (-2.7)
Solar radiation (%) (Annual)	+1.1	Data not provided	+2	+2.6
Wind speed (%) (Annual)	+0.1 (-2.6 to 2.4)	Data not provided	Data not provided	-1.3 (-4.6 to 0.8)
Extreme temperature (Days over 35°C)	+3 to +8 (+5)	Data not provided	Data not provided	+15 to +32 (+22)
Very high or extreme fire risk days	+1	Data not provided	Data not provided	+2.3
Change in runoff (%) (Mean annual runoff)	Reduction in mean annual runoff potentially two to three times greater than projected reduction in rainfall.			
Rainfall intensity (%)	5%	Data not provided	13%	18%
Storm surge	State Government Policy is to allow for 0.3m of sea level rise from 1990 to 2050 and 1.0m to 2100. The Coast Protection Board is able to advise on anticipated sea level rise at specific locations.			
Sea level rise	+0.13 (+0.08 to +0.17)	+0.24 (+0.16 to +0.33)	Data not provided	+0.60 (+0.39 to +0.83)

South East Climate Data (RCP8.5)

Variable	2030	2050	2070	2090
Average temperature (°C) (Annual daily maximum)	+1	1.6	+2.4	+3.2
Average rainfall (%) (Annual)	-4.4	-6.6	-11.9	-15.9
Vapour pressure deficit (%) (Annual)	+10.2	Data not provided	+26.2	+35.8
Potential evaporation (%) (Annual)	+2.9	+ 4.8	+7.1	+9.7
Relative humidity (%) (Annual)	-1.6 to 0.5 (-0.7)	Data not provided	No data provided	-5.8 to -0.8 (-2.7)
Solar radiation (%) (Annual)	+1.3 to no change (no change)	Data not provided	+3.5 to +1 (+3)	+3.3
Wind speed (%) (Annual)	+0.1 (-2.6 to 2.4)	Data not provided	Data not provided	-1.3 (-4.6 to 0.8)
Extreme temperature (Days over 35°C)	+2.2	+4	Data not provided	+8.6
Very high or extreme fire risk days	+1 to +2	Data not provided	+3 to +5	Data not provided
Change in runoff (%) (Mean annual runoff)	Reduction in mean annual runoff potentially two to three times greater than projected reduction in rainfall.			
Rainfall intensity (%)	5%	Data not provided	12%	17.5%
Storm surge	State Government Policy is to allow for 0.3m of sea level rise from 1990 to 2050 and 1.0m to 2100. The Coast Protection Board is able to advise on anticipated sea level rise at specific locations.			
Sea level rise	+0.13 (+0.08 to +0.17)	+0.24 (+0.16 to +0.33)	Data not provided	+0.60 (+0.39 to +0.83)

Appendix 5: Kempsey-Frederickton Bypass flood impact assessment – Roads and Maritime Services NSW, 2008 (Knet: 8935418)

This is an excerpt of the chapter on Climate Change in the RMS NSW Environmental Impact Statement on the Kempsey Bypass project.

7. CLIMATE CHANGE

Climate change impacts have the potential to impact flood planning levels at the site in two ways, either through elevated ocean water levels or via increased rainfall intensities. This section discusses how the potential impacts of climate change should be estimated at the site, with reference to pertinent NSW Government guidelines.

7.1. Sea Level Rise

In October 2009 the NSW State Government released a policy statement (Reference 14) which sought to address how sea level rise should be dealt with in studies seeking to define flood risk in those areas likely to be impacted by sea level rise. This document superseded the NSW Governments "Practical considerations of climate change" (Reference 16) which was released in 2007. From this policy statement document ensued further draft guideline documents one of which entitled "Draft Flood Risk Management Guide" (Reference 15) addresses how sea level rise associated with climate change should be incorporated into flood risk assessments.

The Guide states that:

- The following sea level rise projection benchmarks have been adopted:
  - a sea level rise of 0.4 m by 2050; and
  - a sea level rise of 0.9 m by 2100.
- any flood study for a site likely to be impacted by sea level rise should utilise the 2100 sea level rise benchmark of 0.9 m; and
- any sea level rise must not be accounted for in the 0.5 m freeboard.

The effect of the projected sea level increase by 2100 was assessed by increasing the ocean tailwater boundary for the RUBICON model by 0.9m. Modelling results indicated that the projected increase would not have a significant influence on flood behaviour within the study area. Frederickton is located in the upper reaches of the Macleay Estuary, and tidal influences in the study area are significantly weaker than in lower parts of the estuary closer to the coast. The projected sea level rise by 2100 is therefore not considered to present a significant issue for the project.

7.2. Rainfall Intensity

7.2.1. Projections

It is generally anticipated that one of the impacts of climate change will be relatively more intense rainfall for extreme rainfall events. This issue is addressed in the Reference 16 which was issued in 2007. Table 1 from Reference 16 indicates that the intensity of a 40 year ARI daily rainfall event may increase by 5% to 10% within the Northern Rivers region by 2070, and that evaporation in the region may increase by between 4% and 40% in the same period.

Evaporation is an important consideration because increased evaporation would lead to generally dryer catchment conditions, resulting in lower runoff from rainfall. Mean annual rainfall is projected to decrease, which will also result in generally dryer catchment conditions. The influence of dry catchment conditions on river runoff is observable in climate variability using the Indian Pacific Oscillation (IPO) index (Reference 17). Although mean daily rainfall intensity is not observed to differ significantly between IPO phases, runoff is significantly reduced during periods with fewer rain days.

The combination of uncertainty about projected changes in rainfall and evaporation makes it extremely difficult to predict with confidence the likely changes to peak flows for large flood events in the Macleay River.

In light of this uncertainty, the NSW State Government advice (Reference 16) recommends sensitivity analysis on flood modelling be undertaken to develop an understanding of the effect of various levels of change in the hydrologic regime on the project at hand. Specifically, it is suggested that increases of 10%, 20% and 30% to rainfall intensity be considered.

For example, if it is assumed that a 30% increase in rainfall will result in a 30% increase in peak flood flow in the Macleay at Kempsey, then the peak 100 yr ARI flow would increase from 15,350m3/s to approximately 20,000m3/s, which is almost equivalent to present 200 yr ARI flow (refer Table 1). That is, the current 100 yr ARI flood level for the bypass (6.2 mAHD at Frogmore), would be expected to increase by 0.35m (to 6.55 mAHD, equivalent to the current 200 yr ARI flood level) if runoff was to increase by 30%. By the same reasoning, the current 10 yr ARI flood magnitude would increase to be roughly equivalent to the current 20 yr ARI flood magnitude with an increase in runoff of 30%.

7.2.2. Impact of Projected Changes

The projected increase in rainfall in the study area is 5% to 10% by 2070 for the 40 year ARI event. A rainfall increase of 10%, 20% and 30% for the 100 year ARI event was modelled, assuming parallel increases in infiltration losses of 10%, 20% and 30%, to estimate the projected change in total discharge at Kempsey.

Table 6: Estimated Changes to Peak Discharge at Kempsey

Increase in Rainfall Intensity	**Increase in Infiltration Losses due to Dry Conditions**		
	0%	**10%**	**20%**
	Percentage Increase in Peak Discharge at Kempsey		
10%	16%	13%	9%
20%	33%	29%	25%
30%	52%	46%	42%

Using the upper level projected increase of 10% rainfall by 2070, with no change to infiltration losses, runoff is expected to increase by 16%. This would result in the flood immunity of the Preferred Option being reduced from the 100 year ARI level (plus freeboard) to approximately the 70-year to 80-year ARI level (plus freeboard). Alternatively, the impact would correspond to an increase in peak 100-year ARI flood level at the bridge of approximately 0.2m (based on interpolation between the current 100-year and 200-year ARI events).

7.2.3. Project Response to Climate Change Considerations

There are three basic strategies to manage the effects of climate change within the design life of the project:

1. Design the project initially using projections for the climate-changed environment at the end of the project (for example, design bridges and embankments using the projected 100 year ARI level for 2100);
2. Adapt to climate change by modifying project components in line with climate change observations (for example, by increasing embankment heights at maintenance intervals, perhaps in 40 and 80 years time);
3. Accept the design based on current climate conditions, with the understanding that performance will be reduced by the end of the design life (for example, that inundation might be expected more frequently than every 100 years on average over time).

Given the uncertainty surrounding the climate change projections, and the resulting effect on catchment conditions and runoff volumes, the first strategy is probably not preferable. There would be significant capital outlay at the start of the project, which might not be justified by the benefits.

The second strategy (adaptation) is preferable, as the capital expenditure to upgrade the project would be outlaid closer to the required time. Additionally, it allows any required changes to the project to be refined based on additional observations and projections of climate change impacts on flood frequency at the site. However this approach is only likely to be suitable for the floodplain road embankments, as it is unlikely to be economically feasible for the bridges.

Based on the above, the third strategy is likely to present the most economically advantageous option for the bridge components of the project.

7.3. Summary

The degree of uncertainty surrounding the climate change projections is considered sufficient that it is difficult to assess how the project will be affected by climate change with a high level of confidence. While rainfall intensity in extreme events is projected to increase by 2100, the effect on flooding in large rural catchments may be reduced by increases in evaporation and a reduction in mean annual rainfall, resulting in generally dryer catchment conditions.

An adaptive strategy is therefore considered the best approach for embankment sections of the route, while for the bridges it is likely to be most cost effective to accept that the flood immunity of the route will decrease over time. Based on current projections of changes to rainfall intensity, and assuming only minor changes to catchment conditions, it is estimated that the peak flood level at the bridge will increase by approximately 0.2m.

Appendix 6: Roads and Maritime Services NSW Pacific Highway upgrade (Woolgoola to Ballina) flood impact assessment (Knet: 9273619)

This is an excerpt of the chapter on Climate Change in the RMS NSW Environmental Impact Statement on the Pacific Highway upgrade (Woolgoola to Ballina section).

7.5. Achieving design flood immunity with climate change

7.5.1. Costs of additional earthworks

The additional embankment heights for the Clarence and Richmond River floodplains required to achieve an average flood immunity of 20 years ARI under predicted climate change conditions are not considerable. However, it would result in a substantial increase to the volume of fill material required due to the length of embankments across these two floodplains.

The estimated increase in imported fill for the project if it was to be constructed at these higher levels is:

- To accommodate predicted sea level rise (0.6 metres in 2070): about 140,000 cubic metres, at a cost in the order of $6 million
- To accommodate predicted sea level rise (0.6 metres in 2070) and rainfall intensity increases: about 300,000 cubic metres, at a cost in the order of $12 million.

The increase in embankment height would result in an increase in the total embankment area. However, it would not be necessary to change the project boundary to accommodate this increase in area.

7.5.2. Bridge costs

The large majority of flood conveyance through the project across the Clarence and Richmond River floodplains would be via bridges.

The project includes an allowance for each bridge obvert/soffit to have a 300 millimetre clearance above the 100 year ARI flood level for the passage of debris. Hence, any increase in 20 year ARI flood levels due to sea level rise would not result in bridge obverts/soffits being inundated. However, there would be an increase in the risk of failure of infrastructure, such as handrails, that fails when the road overtops.

Likewise, due to the requirement for the 300 millimetre clearance above the 100 year ARI flood levels, any minor increases in the 20 year ARI flood levels due to sea level rise would not result in the flood immunity at the bridges falling below the target of 20 years ARI.

7.5.3. Pavement rehabilitation

It needs to be noted that the road pavement would require rehabilitation every 30 to 40 years. If necessary this pavement rehabilitation could include raising the pavement by 0.2 metres without substantial changes to the road design. Hence, the road embankment could rise during the life of the project in order to maintain the desired flood immunity if sea levels rise as predicted.

7.6. Conclusions of climate change impacts on project

The following conclusions are drawn from this assessment of climate change and its potential impact on this project:

- The road embankment would be designed to withstand flood inundation. Hence, overtopping of the road embankment would not constitute a failure of the embankment, but rather a disruption to highway traffic

- A projected increase in rainfall intensity of 10 per cent would reduce the flood immunity from 100 year ARI to about 55 year ARI (for the sections not on the Clarence and Richmond River floodplains)
- Sea level rise projections would require increases in embankment height of between 0.09 metres and 0.22 metres across the Clarence and Richmond River floodplain sections to maintain average 20 year ARI flood immunity throughout the project life. Due to the length of the embankment, this is considered to be cost-prohibitive
- The costs of the additional fill required to meet the 20 year ARI flood immunity with the sea level rise projections is estimated to be $10 million. This is considered to be a high cost for the relatively low benefit of attaining 20 year ARI flood immunity
- The flood immunity of the bridges in the project would be much higher than the 20 year ARI flood immunity across the Clarence and Richmond River floodplains and also higher than the 100 year ARI flood immunity in the remainder of the project
- Periodic pavement rehabilitation could assist in raising the embankment levels to maintain the desired flood immunity of the project if sea levels rise as predicted
- The width of the project boundary has been widened, where required, across the Richmond and Clarence river floodplains to allow for any future raising of the embankments by up to 0.2 metres. In most places, the project boundary did not require adjustment as there was sufficient width to accommodate the wider embankment. In some places, the project boundary was widened by up to 1.6 metres to accommodate an increase in embankment height of up to 0.2 metres with a batter slope of one vertical to four horizontal on each side.

In summary of this issue:

- Predicted changes to rainfall intensity (in the order of 10 per cent) are well within the limits of accuracy (in the order of 20 per cent) of current rainfall intensity estimates
- The long-term variability of the frequency of large river flood events indicates that a 10 per cent increase in rainfall intensities would have only a minor impact on embankment flood immunity compared to the impact of natural variability in flood frequencies
- The consequences of under-estimating rainfall intensities for this project are not catastrophic. The road embankment would be designed to withstand flood inundation. Underestimating rainfall intensities would result in more frequent road overtopping than expected and higher outlet velocities and associated scour potential.

Appendix 7: Main Roads WA assessment of the impact of higher temperatures on re-seal frequency

Source:https://www.mainroads.wa.gov.au/BuildingRoads/StandardsTechnical/RoadandTrafficEngineering/Pages/Climate_Change.aspx

Climate Change

Climate change will have a significant impact on transportation, affecting the way we plan, design, construct, operate, and maintain our infrastructure. Decisions taken today, particularly those related to the redesign and retrofitting of existing infrastructure, or the location and design of new infrastructure, will affect how well our network is able to adapt to climate change into the future. Focusing on the problem now will help avoid costly future investments and disruptions to operations.

Main Roads is determined to play a lead role in responding to the challenges and opportunities associated with Climate Change and will progressively review its Standards, Guidelines and Policies to address these. Fundamentally our response will be to employ a "what if" scenario approach to decision making, to better appreciate the risks that might be placed on existing and future infrastructure, and to incorporate greater flexibility to accommodate change where appropriate to do so.

The effects of higher temperatures on re-seal frequency

The life of a well designed and constructed **sprayed seal** is limited to the time when it no longer provides a continuous waterproof surface to the underlying pavement (cracking) and allows surface water to enter the road base, or it starts to lose cover aggregate by traffic attrition (stripping).

Seal life is mainly determined by binder life. Binder life is generally determined by the rate of hardening of the binder which occurs through an oxidation process. Dr John Oliver from ARRB has developed an empirically based bitumen hardening model - ie it is based on actual observations of the rate of bitumen hardening on the road. The most important term in the model is the temperature at the site. The higher the temperature the more rapid the bitumen hardening rate.

However, the viscosity (or hardness) of the bitumen at which distress occurs depends on the minimum temperature in the region. For example, an onsite bitumen could harden to (say) 6.0 log Pa.s in Kununurra, but since the winter is warm, the bitumen would not be hard enough to crack or lose stone adhesion. By comparison, in Albany the winters are colder and the same bitumen would crack, since it would become 'brittle' at the low winter temperature.

Using information provided by the CSIRO, we have applied projected changes in temperature over the next century to the ARRB model and generated a graph of potential seal life reductions for each Region. Of note is that the anticipated reduction in seal life is greater in the generally cooler, southern regions.

The anticipated reduction in seal life due to temperature effects is less than might otherwise be expected - particularly over the next 20 years. However, the issue will be periodically reviewed as more information becomes available, so that adjustments in seal / reseal frequency can be accommodated in the future.

Note that the modelling behind the graph is based upon binder deterioration due to temperature/oxidation. It does not account for bitumen additives, seal damage, or other early problems to a seal that may occur due to, for example, shear caused by heavy vehicles turning at intersections.

Figure 1

Figure 1 summarises the current and anticipated life expectancy of a 14mm chip seal in each of the ten Western Australian Regions. For example, in Great Southern, South West and Wheatbelt South regions, a reduction of 1 to 2 years in seal life may be expected within the next 20 years, and a reduction of up to 5 years by the end of the century, when compared to current reseal frequency.

Appendix 8: Use of Goyder Institute data on the Torrens to Torrens project

Overview

The Torrens Road to River Torrens project is being undertaken as part of a major upgrade of Adelaide's north-south transport corridor to reduce congestion and improve travel times. It comprises a 3.7km section of South Road and includes a lowered non-stop motorway, set approximately 8 metres below the existing road surface.

The depressed road intercepts the level of the water table, hence investigations were required to determine the risk of local groundwater rising above historically observed levels. Given the long design life of the structure, the project team needed to take into account future changes to groundwater levels occurring as a result of changes to rainfall patterns.

> ***"Changing rainfall patterns in the future will influence groundwater recharge rates and the depth to groundwater in Metropolitan areas. Better planning and design now will save costly retrofitting of major infrastructure in the future."***
>
> ***Goyder Institute***

What was done?

The project team obtained downscaled rainfall projections for low-medium and high emissions scenarios from the Goyder Institute, then used models to compare historical depth to groundwater with projected changes in depth to groundwater for the period 2015 to 2090.

What did we learn?

The modelling found that groundwater levels in the vicinity of the depressed road are expected to decline due to rainfall changes under all future climate scenarios considered.

Under the low-medium emissions scenario, groundwater levels are expected to be permanently below observed historic water levels (1980-2014) by about 2055. Under the high emissions scenario, this is predicted to occur by 2035. By 2070 the median projection was for groundwater levels to fall by 3 m at the site due to rainfall decline under a low-medium emission scenario, and by 6 m under a high emissions scenario.

Appendix 9: West Lakes tidal flushing system: preliminary assessment of sea level rise impact

Prepared March 2014 by DPTI: Bridge and Marine Assets

1. INTRODUCTION

The Development Act 1993 (SA Coast Protection Board) and AS4997 Maritime Structures both stipulates that sea level rise is to be considered when designing and/or assessing the future performance of maritime structures and/or facilities.

The West Lakes Tidal Flushing System is an asset that may be affected by the increase of sea level rise.

This report summarises the possible future infrastructure and changes in the operation of the west lakes tidal flushing system in the event of sea level rise. The reader may refer to the West Lakes Flushing System Operational Manual (k-Net: 6065511) for the current infrastructure and operation.

This report does not consider the impact of flooding from stormwater.

2. PREDICTED SEA LEVEL RISE

The South Australian Coast Protection Board provides expert advice on coastal protection and development in South Australia, including protection from the impacts of sea level rise. The Board adopts the following predictions:

Timeline	Predicted Sea Level Rise (relative to 1990)
2050	0.3m
2100	1.0m (further 0.7m rise between 2050 and 2100)

Table 8 – Prediction of Sea Level Rise

The above figures will be used for the assessment of the impact of sea level rise on the West Lakes Tidal Flushing System.

3. BRIEF OVERVIEW OF CURRENT OPERATION

The West Lakes Tidal Flushing System has been designed as a tidal estuarine environment without the extremes of tide experienced in the waters of Gulf St Vincent. The lake is flushed by sea water entering at the southern end, through a 3.5 m diameter pipe, from the Gulf and exiting into the Port River via a culvert under Bower Road, at the northern end of the lake. Refer to Figure 1 for details. Flushing enables the water quality in the lake to be maintained at acceptable levels for recreational use.

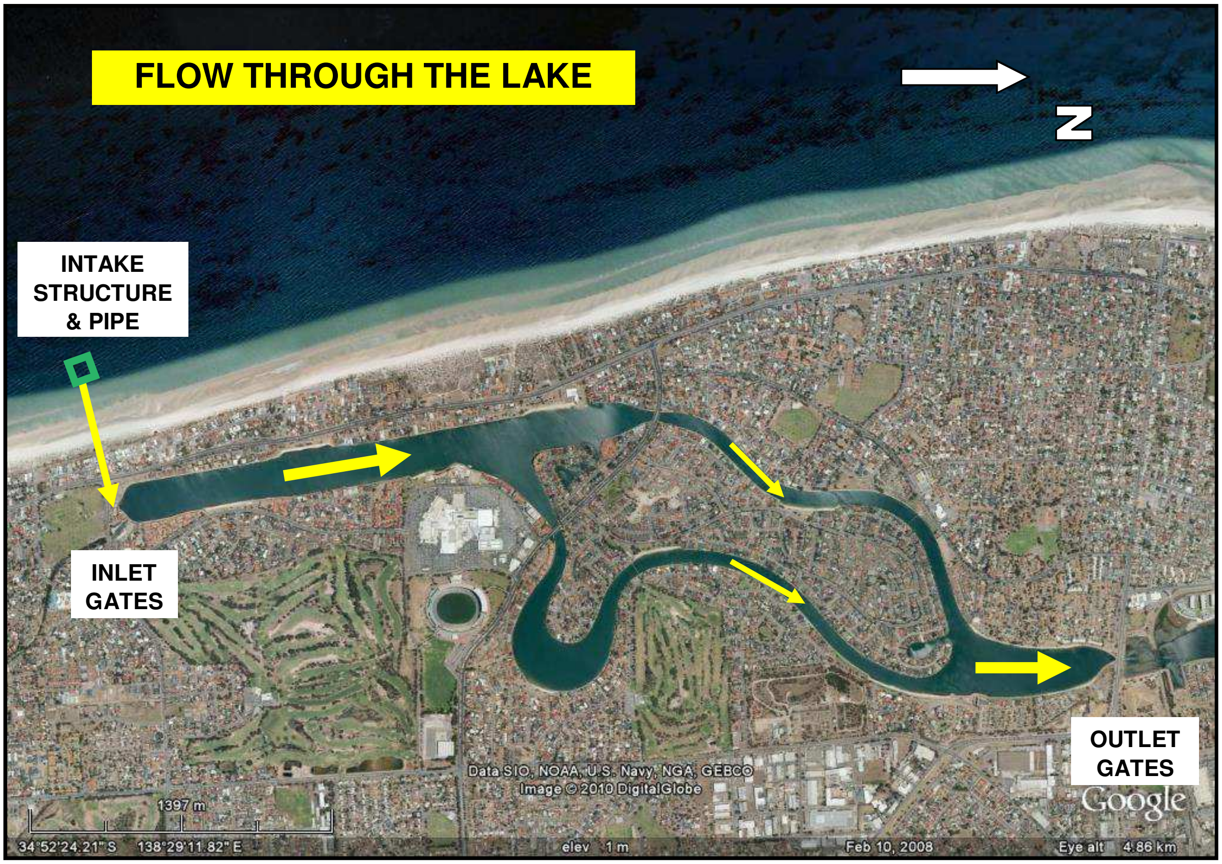


Figure 1 – Direction of Flow for West Lakes

Stormwater runoff from the catchment also flows into the lake via various creeks and drains and can cause considerable rises in lake level at times of heavy rainfall.

The main operation principles of the lake are as follows:

- Normal lake level is controlled by the inlet gates (at Trimmer Parade)
- The inlet gates are opened automatically to allow water flow into the lake whenever the lake is below its preset target height and the sea level is above the lake level at the time
- The inlet gates will close when the lake reaches its target height or the sea level falls below lake level before the target height is reached
- When the level in the Port River falls below lake level the flap gates at the outlet (at Bower Road) are pushed open and water flows out of the lake
- If the lake level falls below the preset low level then the hydraulic slide gates will close to prevent water flowing out. The gates will automatically open once the Port River rises above the lake level.
- Water will continue to flow out of the lake until the level in the Port River rises again and the flap gates are pushed shut

There are normally two flushing cycles of the lake each day, however when there is a dodge tide[5] flushing cycles may be missed.

In order to discuss lake levels and levels of land around the lake edge it is necessary to understand the difference between tide datum and levels on land, which are related to Australian Height Datum (AHD).

AHD has a zero datum based loosely on mean sea level. This is a convenient level for height measurements on land.

Tidal predictions (as given in the tide tables) and measurements of water depth are based on the low tide datum for a particular location.

In case of the West Lakes tidal flushing system, we use the Outer Harbor Tide Datum (OHTD) so we can compare the lake level with the predicted and actual tides.

0 m OHTD = -1.45 m AHD

4. IMPACT OF SEA LEVEL RISE

Figure 2 below shows the recorded current tides of Port River. The light blue straight line represents the high target lake level and the oscillating blue line represents the lake level. From the graph it can be seen that most low tides are well below the high target lake level and therefore the lake can be flushed. However where dodge tides occur there is minimal or no lake flushing.

From the graph below it can be deduced that for some days the lake was not flushed.

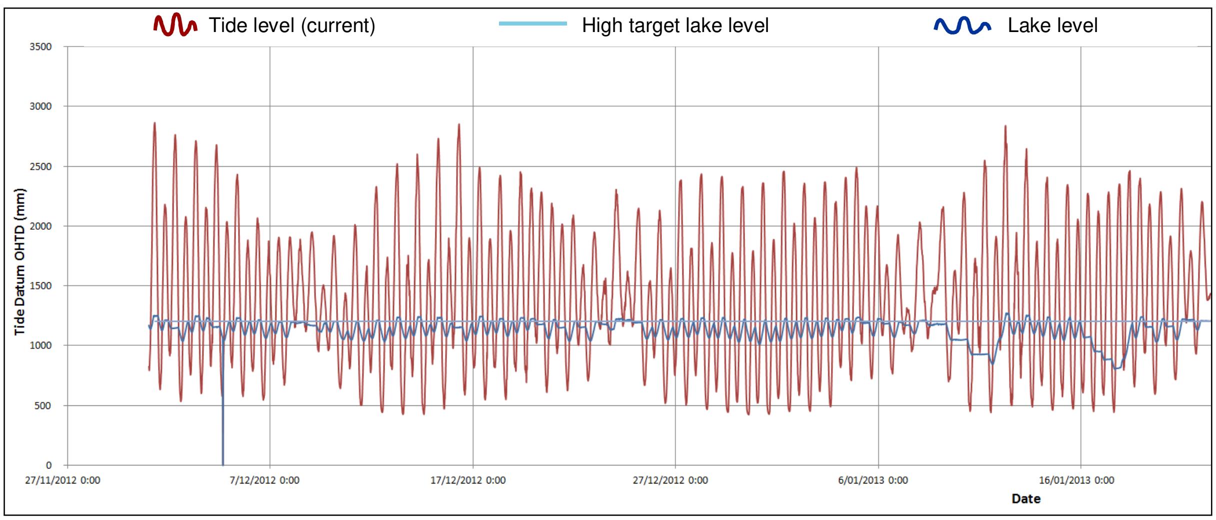


Figure 2 – Direction of Flow for West Lakes

If the sea level was to rise by 0.3m by 2050 then there would fewer low tides below the high target lake level and less flushing may occur. From the graph below it can be deduced that for more extended periods the lake may not flushed at all or the amount of flushing will be significantly reduced.

[5] A dodge tide is a condition where there is very little tidal movement over a number of hours.

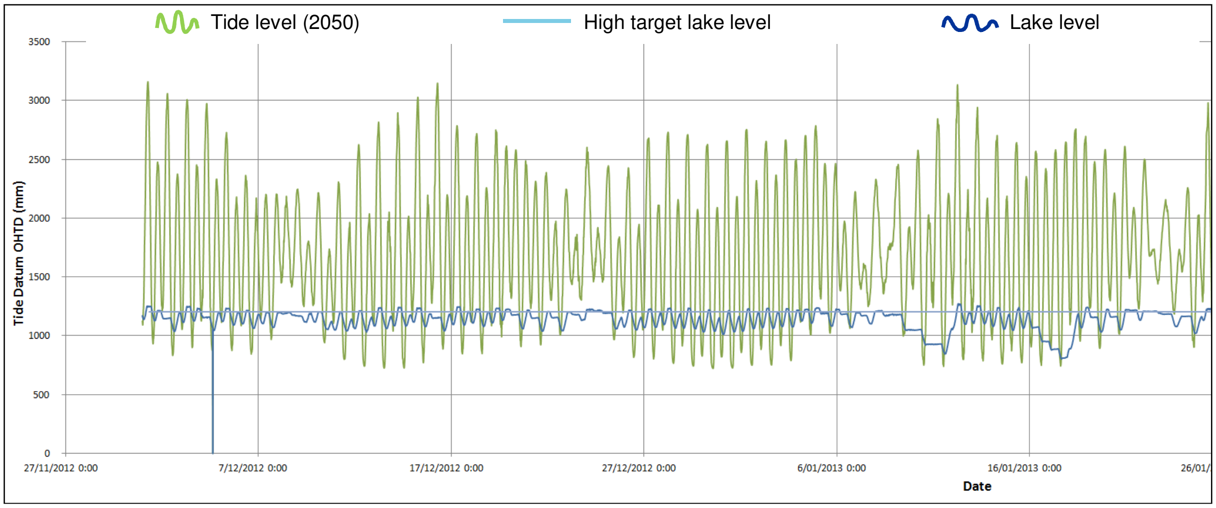


Figure 3 – Direction of Flow for West Lakes

If however the sea rises to 1.0m by 2100 then the low tides will be well above the high target lake level and no flushing will occur. From the graph below it can be deduced that the lake may not flushed at all.

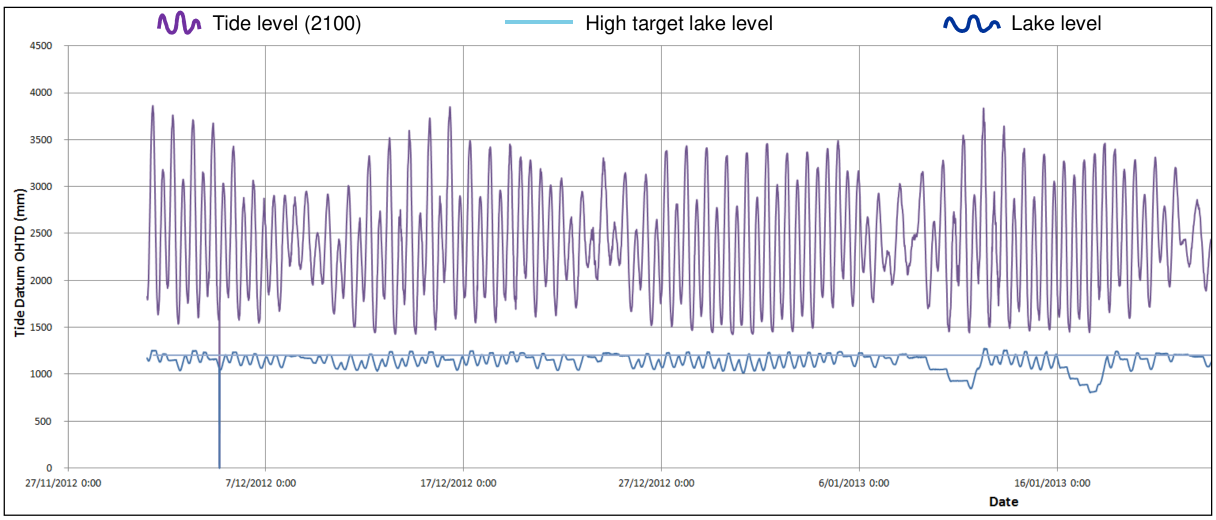


Figure 4 – Direction of Flow for West Lakes

If the sea water rises as predicted in Figure 4 then a new system will be required to assist the flushing of the lake. One such system may be a pump and pipes located at the outlet.

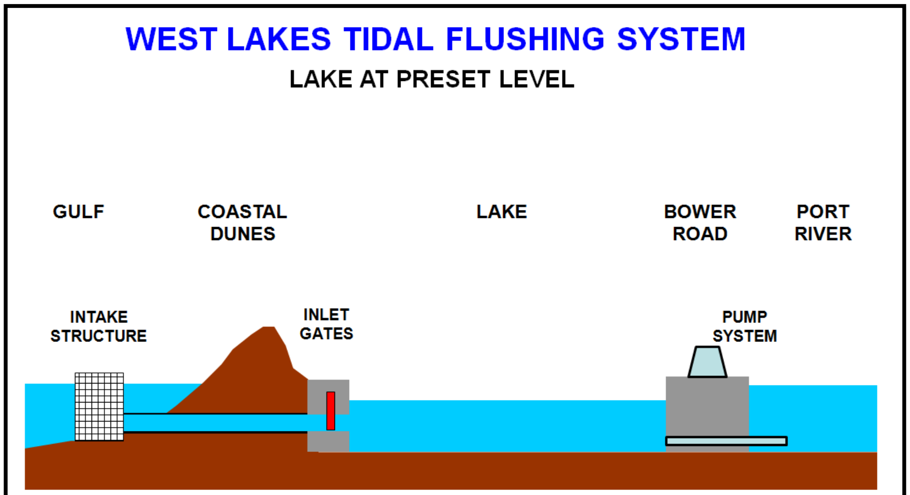
4.1 Possible Changes to Lake Operating Principles

If a pump system is installed at the outlet end the possible operation principles of the lake may be as follows:

- Normal lake level will controlled by the inlet gates (at Trimmer Parade)
- The inlet gates are opened automatically to allow water flow into the lake whenever the lake is below its preset target height and the sea level is above the lake level at the time
- The inlet gates will close when the lake reaches its target height or the sea level falls below lake level before the target height is reached

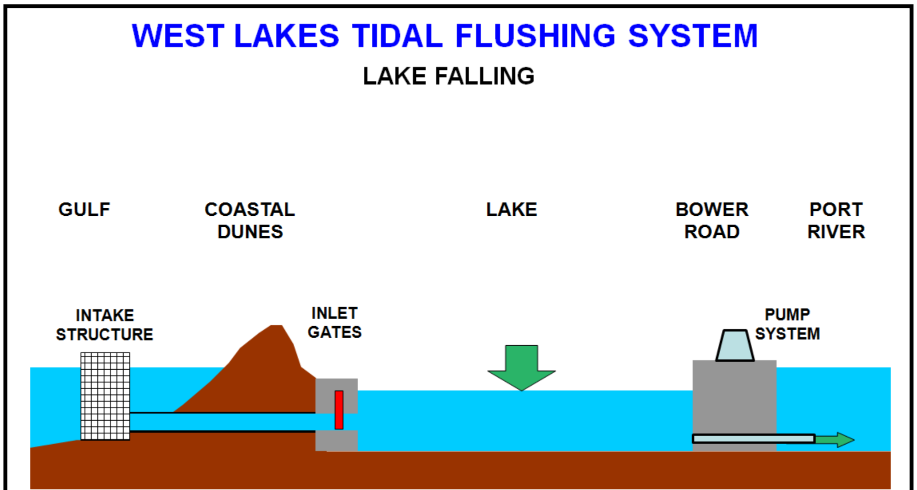
- The new pump will operate to lower the lake level to a determined preset low height. The water is to be pump to the Port River. Depending on the water quality to be maintained in the lake the new pump system may operate twice a day to provide two flush cycles.
- The system can be flushed independently of tides; however the flushing may coincide with the low tide cycles.

Refer to the simplified Figures 5 to 7 showing these principles of operation.



TIDE LEVEL	INLET GATES	LAKE LEVEL	PUMP SYSTEM
HIGH TIDE	CLOSED	PRESET HEIGHT	OFF

Figure 5 – Lake Level at Target Height



TIDE LEVEL	INLET GATES	LAKE LEVEL	PUMP SYSTEM
LOW TIDE	CLOSED	FALLING	ON

Figure 6 – Lake Level Falling

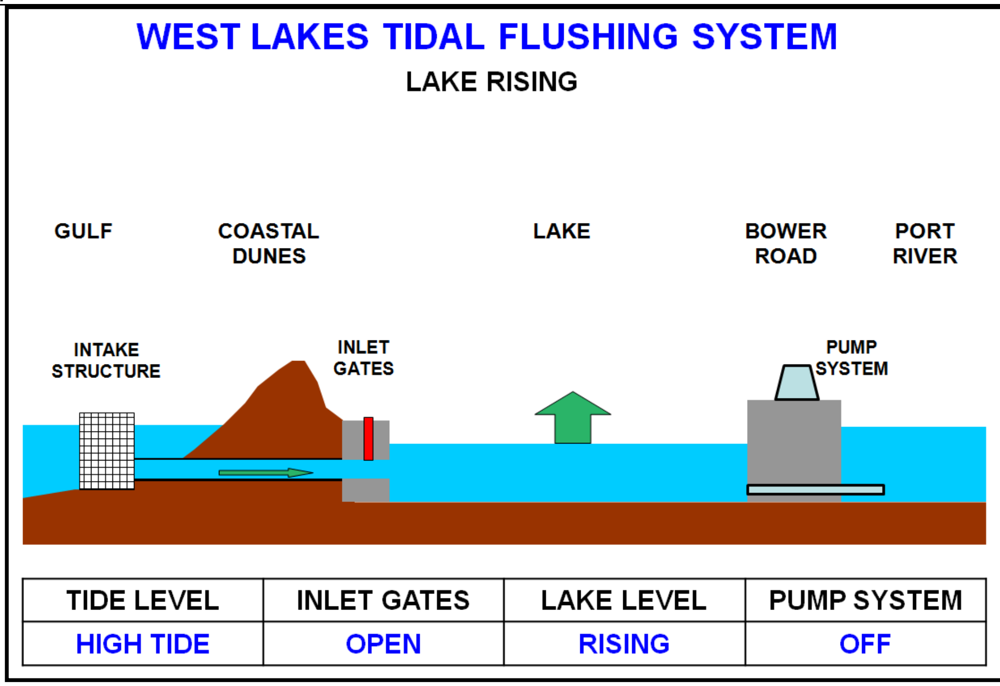


Figure 7 – Lake Level Rising

4.2 External Influences

The current external influences such as stormwater will continue to operate/behave as current unless more infrastructure is built and more stormwater runoff is discharged to the lake system.

5. ROUTINE MONITORING OF LAKE OPERATION

The existing PLC system will need to be modified to control the lake level without operator intervention. The existing operational manual will need to be updated to reflect the new possible changes.

6. INSPECTION AND MAINTENANCE SCHEDULE

The inspection and maintenance schedule for the intake structure and pipe and the inlet compound should remain the same. A new inspection and maintenance schedule will be required for the possible new pump system.

7. PRELIMINARY COST ESTIMATE

A preliminary design will be required in order to estimate the cost of the possible future changes.

8. DISCUSSION

The lake generally is flushed twice daily except when a dodge tide occurs the lake may be flushed once a day or not at all. Throughout out the whole year the lake is approximately flushed 680 times.

The purpose of the flushing is to maintain safe levels of related phytoplankton species present in the water. For the majority of the year, phytoplankton levels tend to remain within safe limits independent of flushing cycles. However, during hot weather when the lake is only flushed once a day, phytoplankton levels can be elevated. This is currently rare.

If sea levels rise as predicted and the number of flushing cycles is reduced, there is the potential for more frequent occurrences of elevated levels of phytoplankton during the summer months. This is likely to be exacerbated by the predicted increase in temperature, as shown in Figure 8:

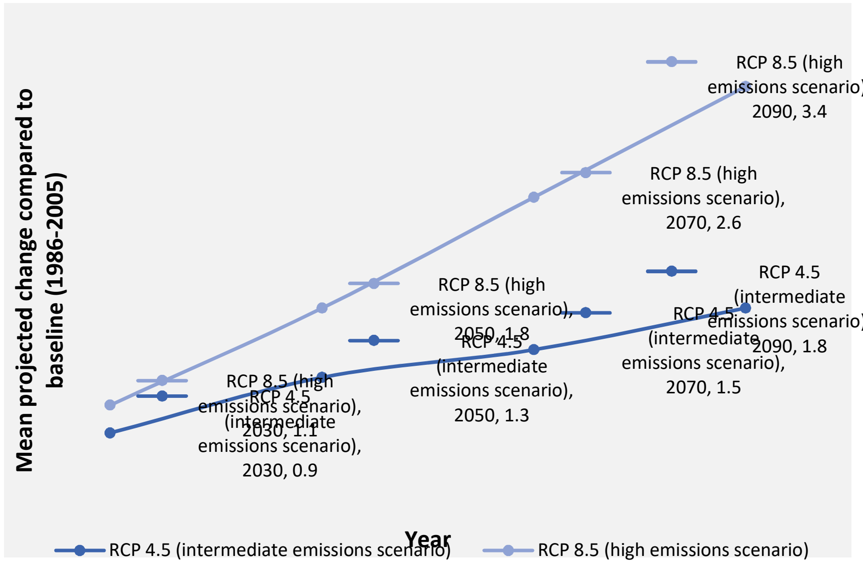


Figure 8 Projected increase in temperature (^{0}C) for Adelaide region

Source: Goyder Institute, 2015, *Climate Projections for Adelaide Mount Lofty Ranges NRM Region*

If elevated levels of phytoplankton are detected, it is recommended that the frequency of water quality monitoring be increased (ie weekly to fortnightly sampling), and SA Health be notified.

An acceptable frequency per year of high levels of phytoplankton is yet to be determined, however if predictions are correct a feasibility study for a new pump system may commence in 2040/45 when the flushing cycle may have reduced to one flush a day (i.e. 340 flushes per year) and where elevated levels of phytoplankton may be occurring more frequently. It is recommended that predictions are kept under review.