Estimating the cost of climate change to Victorian water corporations

A guidance note for the Victorian water sector

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VICTORIA State Government | Environment, Land, Water and Planning

Acknowledgment

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it. We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

We are committed to genuinely partner, and meaningfully engage, with Victoria's Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond.

ISBN 978-1-76105-369-6 **(pdf/online/MS word)**

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Acknowledgements

Marsden Jacob Associates and DELWP consulted widely for this report. We would like to acknowledge and thank all the people we engaged with during this project. The document is better for your input. The input from water sector agencies and other stakeholders during the development of these guidelines is greatly appreciated.

Please address any ongoing feedback to the Manager, Water Sector Climate Change Mitigation and Adaptation, Water and Catchments | Department of Environment, Land, Water and Planning at water.climatechange@delwp.vic.gov.au.

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Acronyms

AAD	Average annual damages
AAP	Adaptation action plan
ARR	Australian Rainfall and Runoff
BAU	Business-as-usual
BoM	Australian Bureau of Meteorology
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DELWP	Victorian Department of Environment, Land, Water and Planning
NPV	Net Present Value
RCP	Representative concentration pathway
WSAAP	Pilot Water Sector Climate Change Adaptation Action Plan

Key Lessons Learned

Drawing on a series of case studies undertaken with three participating water corporations, following are some useful overarching lessons for water corporations that are considering undertaking an assessment or of the costs of climate change.

- Assessing the costs of climate change is an emerging area, likely to require an iterative process and significant ‘learning by doing’.
- For this reason, and due to the inherent complexities of some of the issues being examined, assessing the costs of climate change is likely to be a resource intensive exercise for the organisation, requiring significant inputs in terms of staff time, data and modelling (technical, financial). In some cases, external support may need to be sought.
- A climate change risk assessment (or similar process) is a useful way of identifying priority issues that might warrant analysis of costs.
- Early in the assessment process it is important to understand and clearly define the ‘without climate change’ scenario (generally referred to as ‘business-as-usual’) against which the costs of climate change will be assessed.
- Comprehensive data of a range of types and from a range of sources will be needed to complete a robust cost assessment. Some of this data may already be generated through internal processes. Other data may need to be accessed through external sources and/or through technical modelling.
- Expert elicitation is a useful and valid process for generating some data requirements where empirical data is not available or may not be feasible to generate through other processes such as modelling.
- Due to the nature of the issues being assessed, uncertainties with climate change projections, and often long future timeframes over which costs are being assessed, results of a cost assessment are likely to be subject to significant uncertainties.
- Nevertheless, lack of certainty need not preclude results of a cost assessment being used to assist a water corporation in its planning processes. All decisions are made in the context of uncertainty (see DELWP, 2019).
- Use of statistical techniques in the assessment process, such as Monte Carlo simulation, can help to quantify the uncertainties.
- Prior to undertaking a cost assessment, a water corporation should consider how the results of the assessment are going to be used in the organisation’s planning and decision-making processes.

Introduction

As an industry, the Victorian water sector is seen to be a leader in climate change adaptation. Events such as the millennium drought crystallised the need for forward planning and incorporating climate change planning as a core part of their business. Notwithstanding these efforts, there is scope for water corporations to further improve planning for climate change.

This document provides guidance to Victorian water corporations on assessing the costs of climate change to their operations. Understanding these costs will assist with prudent and efficient investment decisions.

Background

The *Victorian Climate Change Act 2017* requires Adaption Action Plans (AAPs) to be implemented from 2021 for seven core sectors including the water sector. Prior to development of the plans, three pilot AAPs are being undertaken to test the new sector-based approach to adaptation, including the Pilot Water Sector Climate Change Adaptation Action Plan (WSAAP).

The Department of Environment, Land, Water and Planning (DELWP) is delivering the pilot WSAAP in collaboration with other water sector organisations. One of the actions put forward by the WSAAP is to estimate the costs of climate change on water corporations and/or their impact on customer service levels. It is expected that this information will be used by Chief Financial Officers, Executive Boards of water corporations, and or officer level staff members to inform decision making and training. It will also be used by other finance and climate change staff within the water sector and Victorian State Government.

Why assess the costs of climate change?

Victoria's climate has become warmer over the past few decades and drier in winter and spring. These trends are projected to strengthen over the coming decades (Grose et al. 2015, Timbal et al. 2015) and are likely to be associated with increases in extreme weather events including:

- Drought frequency, duration and severity
- Heatwave duration and intensity
- Frequency of extreme bushfire weather
- In some areas, intensity of heavy rainfall events and associated flooding.

These changes have the potential to severely impact on the operations of Victorian water corporations:

- Depending on the nature of impacts and ongoing efficiency improvements, water corporations may need to invest more to maintain or improve service levels, where this is possible. Alternatively, in consultation with customers, they may need to look at ways of changing how services are provided, in some circumstances, lowering levels of service.
- Climate change may also affect the operations of water corporations and their compliance with industry standards that are regulated by government agencies.

Given these impacts, it is important that water corporations understand the potential costs of the impacts to enable prudent and efficient investment decisions.
Importantly, by assessing the costs of climate change, water corporations will be better placed to engage with customers and the broader community on the issue:

- the risks associated with climate change;

- the complexities and uncertainties involved in assessing those risks; and
- the adaptation options available for responding to those risks.

This document

This guidance note provides high level guidance to Victorian water corporations on assessing the costs of climate change to their operations. The guidance note has been developed drawing on experience from a series of case studies undertaken with water corporations in Victoria. The processes set out in this document should be seen as preliminary steps of a more wide-ranging process of assessing and responding to the potential impacts of climate change. The guidelines include:

- an overview of the broad framework though which the costs of climate change will often be assessed; and
- step by step guidelines on how to go about assessing the costs of climate change.

Interspersed through the guidelines are a series of boxes that discuss specific issues relevant to assessing the costs of climate change. These include:

- the climate change risk assessment process;
- analytical tools that can be applied to assessing costs in the context of uncertain future climate changes and their impacts;
- key data requirements and sources; and
- the concept of discounting

Legend:

1. Sea level rises
2. More heat waves
3. Temperature increases
4. Lower average rainfall
5. More frequent and severe storms
6. More intense storms
7. More frequent bushfires
8. More frequent and severe droughts
9. More frequent and extreme flash flooding
10. Heavier rainfall may lead to sewer overflows, impacting receiving water
11. Limited access to water for agriculture, parks, gardens and recreation areas during drought.

Impacts of climate change on the water sector as outlined in the Pilot Water Sector Adaptation Action Plan

Overarching framework

This section presents an overarching framework for assessing the costs of climate change impacts. We anticipate that this framework can be applied across the assessment process for most climate change impacts being considered.

Costs of climate change defined

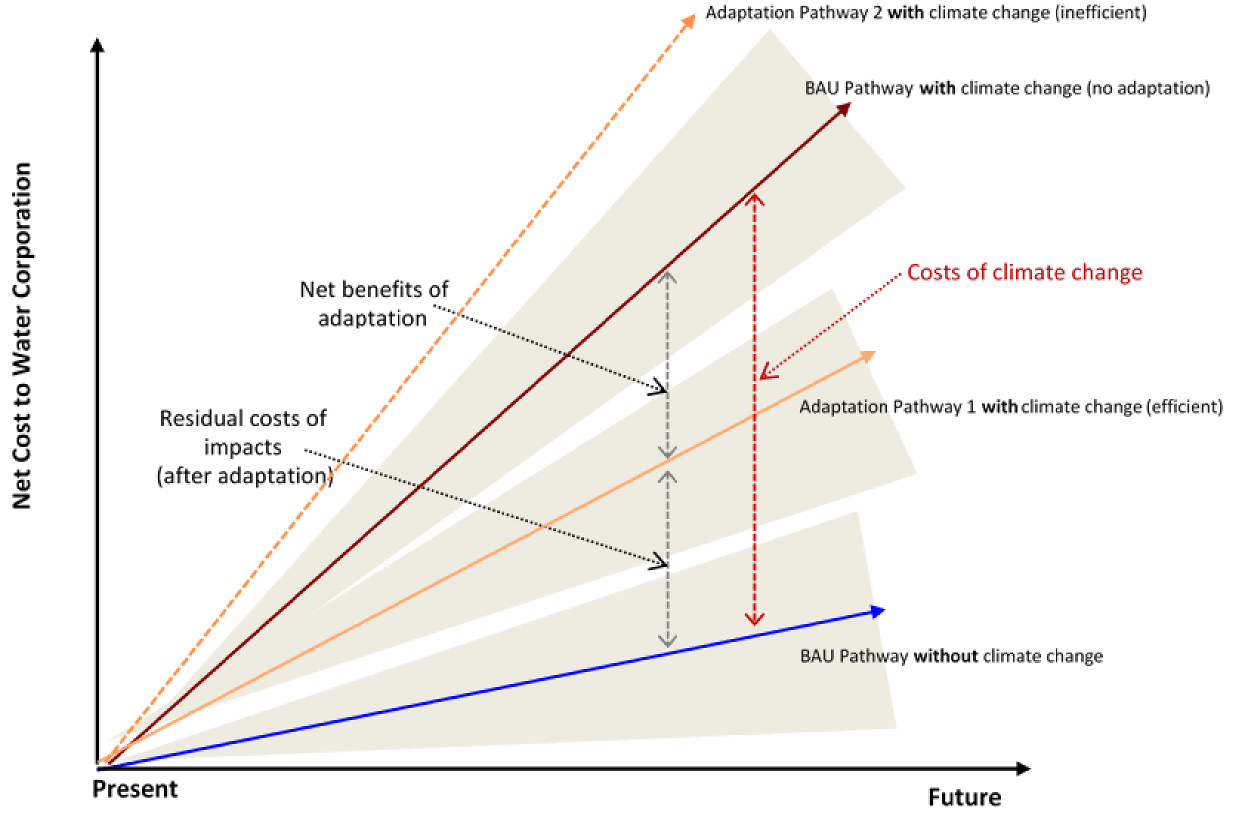
The costs of climate change to a water corporation should be estimated assuming a business as usual (BAU) operating future. It is important to note that **BAU is not a fixed or unchanging operating future**. Rather, BAU assumes that a water corporation will not undertake activities in the future, that are specific to the relevant climate change impact, beyond those that have already been implemented or are definitely planned. Other aspects of a water corporation's operations will be changing however, and those changes should be factored into BAU settings. The costs of climate change to water corporations can then be assessed by comparing the costs of these activities under a "current climate" scenario (which is a realistic assessment of what the future will look like in the absence of climate change), with the costs of these activities under "climate change" scenarios.

The BAU cost pathway is illustrated by the red line in Figure 1. The area under that line (dotted red line) represents the costs of climate change.

Quantification of the costs incurred under the BAU pathway allows water corporations to make decisions on appropriate adaptation pathways that are more financially or economically efficient[1] than the BAU pathway. It should be noted however, that considerations other than efficiency (such as community preferences, government policy etc) will also frame decision making.
Figure 1 shows that there may be various adaptation pathways available to water corporations. Some adaptation pathways may result in higher net costs to the corporation than what would have been incurred under BAU. (e.g. Pathway 2).

[1] Financial analysis assesses the direct financial impacts of an activity or event on an individual or an organisation (e.g. a water corporation). Economic analysis assesses the broader community impacts, direct and indirect, tangible and intangible, including environmental and social impacts.

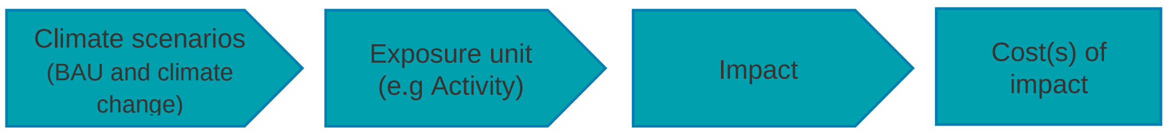
Figure 1: **Cost of climate change impacts defined**



Quantifying the costs of climate change

The Intergovernmental Panel on Climate Change (IPCC) *Technical Guideline for Assessing Climate Change Impacts and Adaptations* (IPCC 1994) provides a simple but nonetheless useful framework for identifying and quantifying the impacts of climate change. This framework is illustrated in Figure 2. This assessment framework is adapted in more detail to suit the water industry, as illustrated in Figure 3.

Figure 2: **Cost of climate change impacts defined**



Water corporations carry out various activities to deliver agreed levels of service to their customer base. The activities are the exposure units that are impacted by climate change. Under the BAU pathway, each activity incurs a certain cost to deliver the agreed level of service. Under climate change the activities may be impacted and therefore a water corporation may need to increase the expenditure on that activity to maintain the agreed level of service. Alternatively, a water corporation may reduce or change the delivered level of service or the activities undertaken to achieve it with agreement from the customer base.
We propose a risk-based approach to quantifying the impact of climate change to each of the activities carried out by water corporations. The typical definition of risk is illustrated by the equation below.

Risk = consequence x likelihood

This definition of risk is consistent with the Australian and International Standard (AS/ISO 31000) and applied in established guidelines on climate change and risk e.g. (Broadleaf Capital and Marsden Jacob Associates, 2006).

The risk based approach to assessing the costs of climate change takes this definition a step further by seeking, where feasible, to identify and quantify the change in consequence and/or the change in likelihood of relevant climate change impacts on water corporation activities relative to BAU and costing those impacts. This is defined in the equation below.

Cost of climate change = Δ consequence x Δ likelihood

Applying this equation for a given impact enables an expected value (EV) of the cost of climate change to be estimated, defined as a probability weighted cost.

Scope of the assessment

Scope establishes boundaries for an assessment, i.e. what is to be included in the analysis and what is excluded. Specific aspects of the scope will vary with each assessment (see Step 0 in step by step guidance section), but there are certain aspects of the scope that we recommend should always be followed.

Water corporation activities

Figure 3 outlines the various activities that a water corporation may undertake in delivering desired levels of service to customers. It is important to note that not all activities shown in the framework will necessarily be carried out by every water corporation. The important point is that any of the relevant activities listed here might be considered by a water corporation when assessing the costs of climate change.

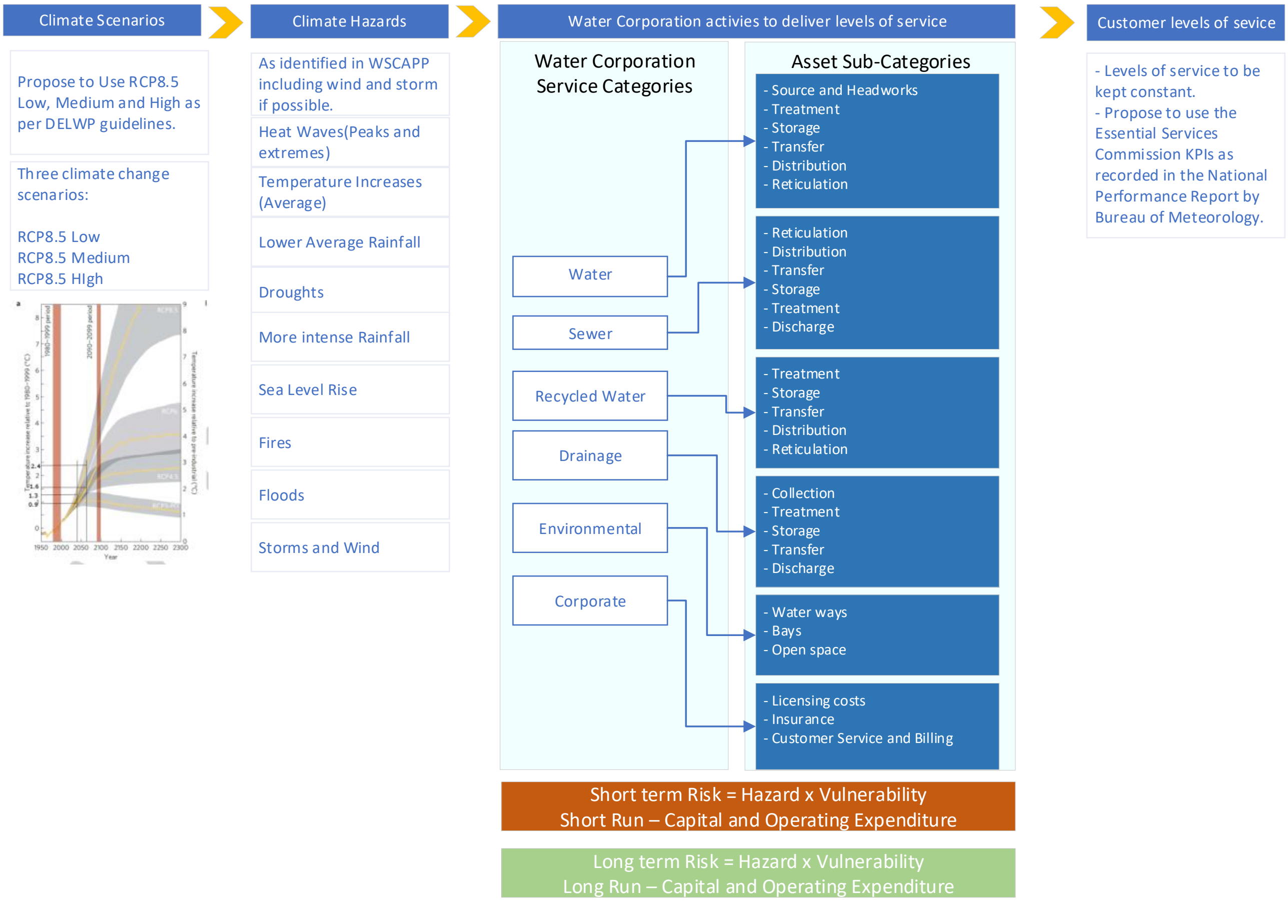
The activities may be categorised by the type of service such as water, sewer and recycled water and then further segmented to show the asset function. The asset function can then be even further segmented into civil, mechanical and electrical (this segmentation is not shown in the figure).

It is important to note that each segmentation incorporates an additional level of granularity to the assessment and in turn adds a level of complexity that requires additional data.

A quick note on energy and greenhouse gas emissions in the water sector

Water corporations have management plans that seek to reduce greenhouse gas emissions. Decisions on the method of purchasing or generating electricity is typically influenced by their greenhouse gas strategy. The impacts of climate change on energy costs will translate into a water corporation's costs of delivering their levels of service. Although this is an indirect impact of climate change, it is an activity and impact that water corporations might also want to consider.

Figure 3: Climate change impact assessment framework



Customer levels of service

When assessing the costs of climate change, we recommended that water corporations initially measure the costs incurred to maintain the same levels of service under climate change as under BAU. This aligns with a risk-based approach in that we are quantifying the additional cost to a water corporation to insulate the customer based from further risk exposure due to climate change.
Additional scenarios can be tested by estimating the costs to a water corporation if certain levels of service were reduced with the agreement of the customer base.

Customer service levels and their use in quantifying the impacts of climate change.

It is generally appropriate to use the currently measured key performance indicators monitored by regulators such as the ESC. These metrics are consistent across most water corporations within Victoria. The metrics are recorded by the Bureau of Meteorology and published annually through the National Performance Report (Bureau of Meteorology, 2018).

Broadly, the levels of service describe the agreements that the water corporations have in place with their customers about the expected standard of the service. These may be described and declared in corporate documentation such as the corporate plan, annual report and regulatory pricing submission.

Costs of climate change

Analysis of the costs of climate change should, in the first instance, focus on the financial costs incurred by a water corporation, as these costs are generally the easiest to quantify and can be most directly linked to a water corporation's operations. Financial costs are the tangible, direct costs incurred by a water corporation in providing the desired level of service to its customer base. They include:

- Capital expenditure on assets including land
- Operational and maintenance expenditure

- Loss of revenue
- Corporate costs (insurance, licencing).

In some circumstances however, where indirect or intangible costs are likely to reflect on a water corporation's performance or its standing in the community, a water corporation may choose to also consider these broader costs. Direct but intangible costs include health impacts to employees, and contractors resulting from impacts of climate change on a water corporation and loss of service to customers. Indirect, but readily measurable costs include financial costs to the community resulting from loss of service. If impacts to the community are captured in the analysis, then the analysis escalates from a financial assessment to an economic assessment. This has implications for how the results will be presented (see Step 0 in step by step guidance section).

The definition of the costs definitely included in the scope, possibly included and likely to be excluded are provided in Table 1.

Table 1 Cost definition framework

	Direct	Indirect
Tangible	- Capital expenditure - Operating and maintenance expenditure - Electricity - Labour - Chemicals and other materials - Revenue loss - Corporate Changes in management overheads Insurance	- Emergency response costs incurred to other government agencies assisting water corporation - Community financial costs resulting from loss of service - Loss of productivity resulting from loss of service
Intangible	- Death, injury, stress (to employees, contractors) - Loss of service to customers (if service levels cannot be maintained)	- Inconvenience and stress (to customers) - Health and safety (customers and community)

Financial	Economic		
Definitely in scope	**Possibly** in scope but difficult to value	**Possibly** in scope but difficult to attribute to water corp.	**Unlikely** to be in scope, difficult to attribute and value

Source: *Marsden Jacob Associates, drawing on Bureau of Infrastructure, Transport and Regional Economics, 2001*

Short and long run costs

It is important to understand the temporal nature of costs incurred by each water corporation. We propose that both short run and long run costs of climate change impacts be quantified in the analysis.

Short Run Costs

Short run costs typically include operational expenditure to provide the current levels of service without increasing capacity. In the short run, water corporations provide the levels of servicing by using the activities and options currently available to them within their current capacity.

It is particularly important to understand and quantify short run costs in the context of climate change to capture the impacts of managing extreme events. In the short run, water corporations would not have the time to introduce new assets to mitigate the impact of extreme events. Therefore, a climate change event would incur additional operational expenditure in the short term. The potential increase in costs resulting from additional emergency response activities is included in short run costs.

> ***Short Run Cost example***
>
> In a dry summer period where water storages are low, a water corporation may manage the use of the existing water by optimising the transfer of water between existing storages, propose demand reduction interventions or other short term measures that seek to conserve the use of water.

Long Run Costs

Long run costs typically include capital and operational expenditure that is invested to increase a water corporation's current capacity. Investments to increase capacity may occur with growth in the customer base or a reduction in traditional sources of supply.

With respect to climate change, the impact on long run cost implications become relevant in scenarios where the levels of service can no longer be delivered without increasing the capacity of the system.

> ***Long Run Cost example***
>
> A water corporation may invest in a new water source e.g. a desalination plant to secure sufficient water supply to meet growing demand over the longer term. The decision to invest in a desalination plant rather than a traditional approach may be influenced by climate scenarios that predict dryer stream flow scenarios than historical observations.

Time periods

To enable water corporations to make decision about suitable adaptation pathways, it is important to understand the time period when impacts and resulting costs may occur. Consistent with planning horizons of water corporations and climate change projections, we recommend defining the periods as follows:

- **Short term** 5 - 10 years (to about 2030)
- **Medium term** 10 - 30 years (to about 2050)
- **Long term** 30 - 50 years (to about 2070)

Climate scenarios

The costs of climate change to a water corporation are assessed by comparing costs that can be expected to occur under a BAU cost pathway to the costs that could occur under one or more climate change scenarios. This requires establishing a BAU or ''current climate'' scenario and ''climate change'' scenarios.

Current climate scenario

The current climate scenario is described in the recent work completed by DELWP, in conjunction with CSIRO to provide guidance for assessing water resource availability for Victorian Water Corporations. The guidance paper recommends that current climate be defined as the observed climate baseline from 1975 to the present day (Department of Environment, Land, Water and Planning, 2016). This definition is likely to be appropriate for articulating the BAU climate in some circumstances, including analyses examining changes to average rainfall. For other climate variables, the baseline period against which climate change projections are defined by the CSIRO is generally the 20 year period 1986-2005 (see following section).

Climate change scenarios

DELWP in collaboration with CSIRO, developed guidelines for *assessing the impact of climate change on water supplies in Victoria* in 2016. The guidelines outline climate change scenarios that are applicable for use in water resource planning by Victorian water corporations (Department of Environment, Land, Water and Planning, 2016). The guidelines have been used by urban and regional Victorian water corporations in developing long term water resource plans for their Urban Water Strategies.

We recommend use of these guidelines by water corporations, especially if the climate change impacts being costed are specific to water resource planning. We note however, that at the time of writing, the guidelines are being reviewed and an updated version for guidelines for *water availability* will soon be available.

The DELWP guidelines propose the use of three future scenarios based on representative concentration pathway (RCP) with the highest concentration of greenhouse gases. This pathway known as RCP8.5, has been adopted in line with the recent historical trajectory of greenhouse gas concentrations. Consistent with this pathway, the following scenarios are proposed for use when assessing the costs of climate change:

Current climate: Average climate of the current period

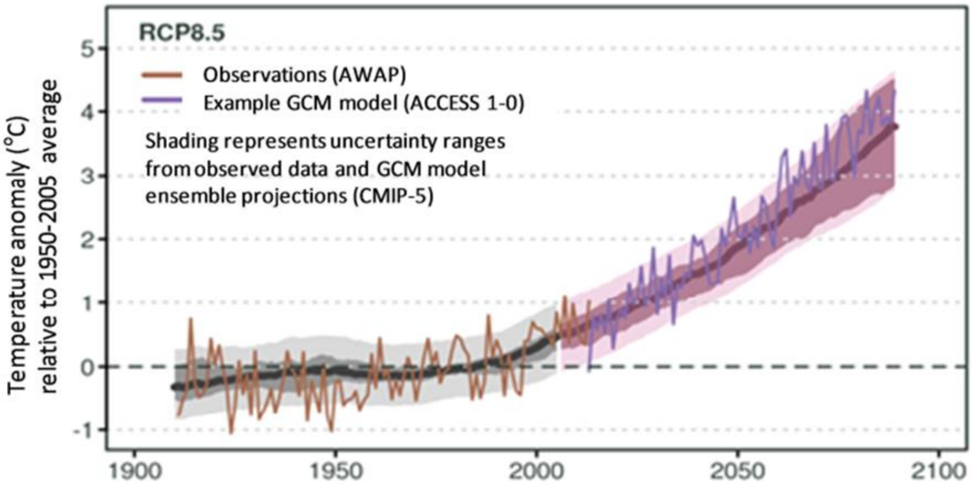
Future Scenarios:

- RCP8.5 Low
- RCP8.5 Medium
- RCP8.5 High

Additional Scenario: Step change

The temperature anomaly expected within the RCP8.5 scenario is shown in Figure 4 below.

Figure 4: Projected global temperature changes under RCP8.5



The low, medium and high climate change projections represent the 10th percentile, median and 90th percentile values projected to exceed, within the RCP8.5 emissions pathway, based on the 42 global climate models. The guideline also recommends the use of a “step change” scenario that captures the seasonal variations observed through the millennium drought and wetter than average periods post drought.

Climate change projections

Climate change projections for a wide range number of climate variables have recently been developed by CSIRO for Victorian regions. Climate variables covered include:

- average, minimum, maximum temperatures and extreme temperatures;
- relative humidity;
- pan evaporation, solar radiation;

- average rainfall; and
- extreme rainfall.

This information is available at: https://www.climatechangeinaustralia.gov.au/en/climate-projections/future-climate/victorian-climate-projections-2019/. The projections are accompanied by guidelines for their application.

Projections for additional climate variables are also available through the *Climate Futures* tool at: https://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-futures-tool/projections/. These include:

- drought frequency;
- soil moisture and runoff;
- fire weather;
- windiness, extreme winds and storms; and
- sea level rise.

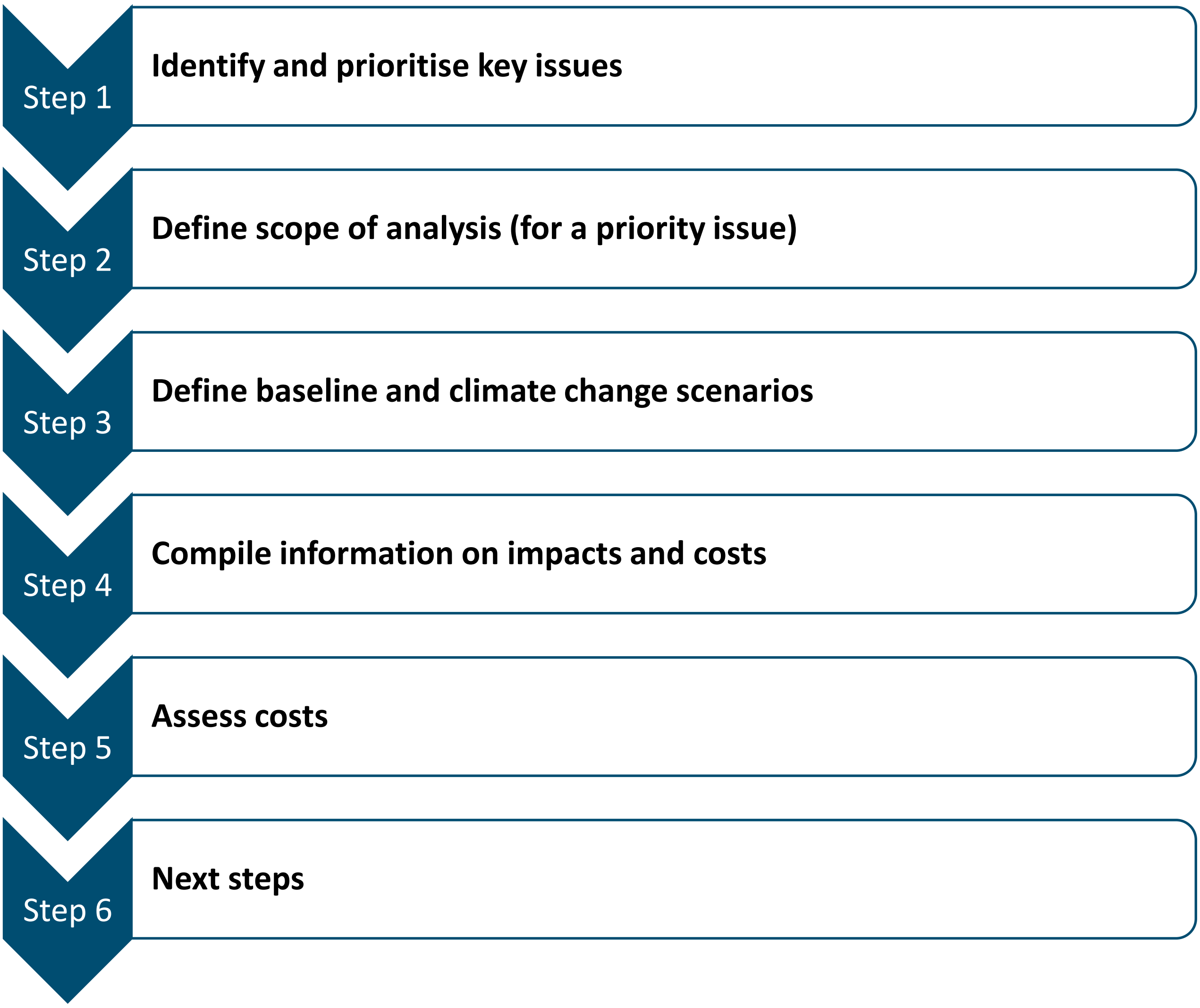
These climate future projections, although regionally based, do not have the same high level of resolution as the Victorian projections. We note that climate change projections are not necessarily available for all climate variables or hazards - at least not at the level of detail or in the format required to assess the costs of climate change. It is possible that projections are available for the hazard in question but, for various reasons, have not been included in published material. CSIRO will need to be consulted on whether additional information is available.

Step by step guidance

This section goes through, step by step, the process of assessing the costs of climate change. The steps draw on the framework outlined in the previous section. Six main steps have been identified (Figure 5). We discuss each of these steps in turn.

Although the steps will be undertaken more-or-less sequentially, it is important to note that the process will be an iterative one, often requiring backtracking and revisiting steps. These steps are expanded upon in subsequent sections of this guidance document.

Figure 5: Steps involved in assessing the costs of climate change



1. Identify and prioritise climate change impacts

> ***Key points for step 1***
>
> - Prioritising climate change impacts will aid an efficient assessment process
> - Climate change risk assessment is a suitable method for identifying and prioritising impacts, that could warrant further analysis, including cost assessment
> - It is important that a climate change risk assessment is integrated within broader strategic risk assessment and planning frameworks and is updated periodically

For water corporations, assessing the costs of climate change has the potential to be a very resource intensive exercise. Before undertaking cost assessment therefore, water corporations should consider implementing an exercise of identifying climate change impacts on their operations and prioritising key climate change impacts.

A range of possible techniques are available for identifying and prioritising climate change impacts, but we suggest that an initial, high level risk assessment is the most appropriate (see Box 1).
The risk assessment should be undertaken in accordance with Standard AS/NZS IS 31000:2009 for Risk Management. However, elements need to be introduced into the risk assessment process that reflect the unique elements of climate change as a driver of risk. These include:

- the use of climate change scenarios to help identify and understand the hazards and associated impacts and risks posed by climate change to a water corporation's assets and services; and
- assessing risks at three points in time consistent with the time periods.

Outputs of the risk assessment will be used as a basis for selecting priority risks, potentially requiring further analysis, including assessment of their costs.

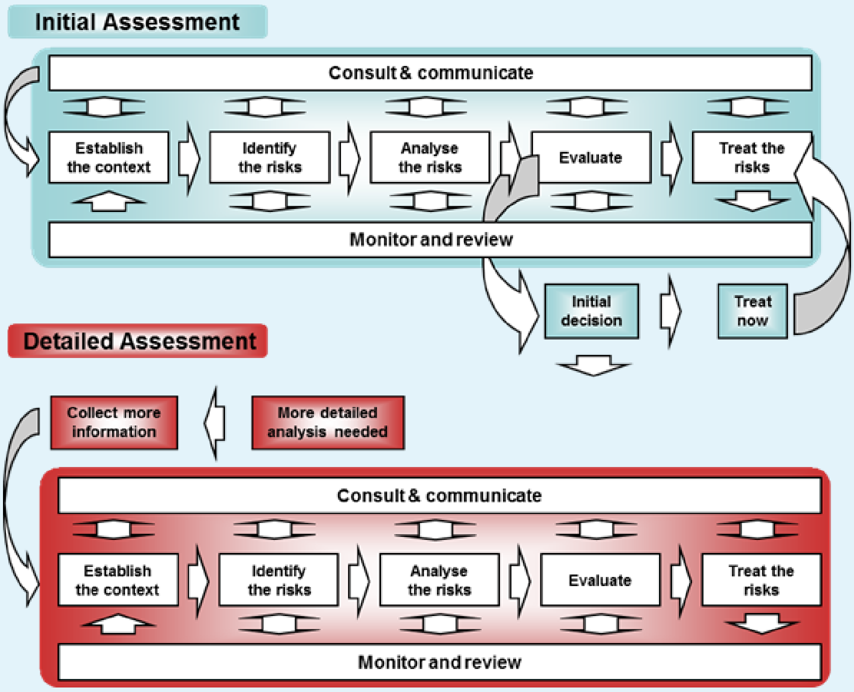
It is important that a climate change risk assessment is integrated within broader strategic risk assessment and planning frameworks and is updated periodically.

Box 1: Climate change risk assessment

As discussed earlier in this document, **risk** is defined as the likelihood and consequence of an outcome (in this case an impact driven by a climate related hazard). A risk assessment can be undertaken at two levels, an initial assessment or a detailed analysis (Figure 6):

1. An initial assessment is a qualitative process that identifies and sifts risks quickly, followed by treatment planning for those risks that clearly require it.
2. A detailed analysis is used where additional information is needed to determine whether treatment (adaptation) is required and/or what form of treatment to adopt.

Figure 6: Initial and detailed risk assessment



In most cases, an initial, high level risk assessment will be a sufficient level of analysis to inform a water corporation whether a climate change related impact has the potential to be significant, possibly warranting more detailed assessment. Generally speaking, a detailed assessment will be substantially more resource and data intensive exercise aimed at quantifying a risk. Assessing the costs of climate change is part of that detailed assessment process.

2. Define scope of analysis

Key points for step 2

- Identify the purpose of the assessment.
- Work through other elements of the scope
- It may be useful to frame a single question that pulls together these elements

At the commencement of the scoping exercise it will be important to identify the purpose of the assessment. Why is the cost assessment being undertaken and who will use results of the assessment? Is the assessment intended to assist with planning processes or perhaps to inform a submission (e.g. to regulators)? Alternatively, is the assessment merely part of an initial scoping exercise? Answers to these questions will be important for helping to define the overall scope of the analysis and for allocating resources.

Once the question of 'why?' has been answered, defining the scope will involve working through a number of other elements:

- What **climate-related hazard or hazards** are the cause or potential cause of the impact being assessed?
- Which **activity** or activities are being impacted by the hazard(s), including the specific elements of those activities?
- **What types of costs** will be affected by an increase in the frequency or magnitude of the hazard(s), given the need to maintain **levels of service**? What is the potential **scale of costs**?
- What is our current **level of understanding** of the likely type and scale of costs? What **additional information** will be required?
- Given the type and scale of costs, our level of understanding of those costs and the additional information required, what **levels of resourcing** (internal and external) are likely to be needed for the analysis? Is allocation of these resources to the analysis warranted given the intended purpose of the assessment?
- What is the **timeframe** over which the cost assessment will be undertaken (note we recommend, as a general rule, that costs should be assessed over the short term, medium term and long term)?

A useful way of framing the scope is to pose a question that pulls together all of these elements. Examples of framing questions are provided in Box 2.

Box 2: Examples of questions used to help frame an assessment of the costs of climate change

- *Given a warmer, drier climate in the future (2030, 2050, 2070), leading to increases in demand and reduced supply from current water sources, what will be the additional capital and operating costs to our water corporation of maintaining a reliable water supply?*
- *Given a warmer, drier and more variable climate in the future (2030, 2050, 2070), leading to increased ground movement and associated impacts on water pipes, what will be the additional capital and operating costs to our water corporation of maintaining pipes?*
- *Given a warmer, drier and more variable climate in the future, leading to an increase in the frequency and severity of catchment bushfires and debris flow contamination events, what will be the additional capital and operating costs to our water corporation of maintaining the region's water security?*

3. Define baseline and climate change scenarios

Key points for step 3

- A clearly defined baseline and climate change scenarios are critical to understanding data requirements and potential methods to be applied to the assessment
- The baseline (BAU cost pathway) does not denote a static future
- Climate change scenarios should be compiled from projections for climate hazards/variables developed by the CSIRO for Victorian regions

Establishing the baseline and climate change scenarios is, in some respects, an extension of the scoping exercise. Like the scoping exercise, clearly defining the baseline and climate change scenarios is critical to understanding data requirements and methods employed to assessing costs.

Baseline

The baseline, or BAU cost pathway, is the pathway that can be expected to be taken in the future, in the absence of climate change. In this respect the baseline assumes:

- Continuation of activities, investments, policies (e.g. levels of service), anticipated in the absence of climate change.
- Continuation of the current climate and levels of impact associated with that climate.

Crucially, in relation to the second point, the baseline is rarely static. Levels of activity (e.g. supply of water to meet changing demand), the extent of assets exposed to climate related hazards, and the numbers of customers to be serviced can all expect to change over time due to population, economic growth and other factors. This growth should be incorporated into the baseline using best available projections.
As detailed in Step 4, once the baseline has been defined, it will be necessary to collate data relevant to the baseline. This could include historic information on climate related hazards relevant to the impact being assessed and costs associated with those hazards, as well as projections of the cost pathway in the absence of climate change.

Climate change scenarios

We recommend the use of three climate change scenarios with each cost assessment: Low, Median and High. The sector could draw on scenarios on climate change projections developed for Victoria by the CSIRO (see DELWP 2016 for water sector specific guidance, as well as recently released Victorian Climate Projections 2019). For example, you can find projections for:

- 10 Natural Resource Management (NRM) regions in Victoria – Barwon, Central Highlands, Gippsland, Goulburn, Great South Coast, Greater Melbourne, Loddon Campaspe, Mallee, Ovens Murray, Wimmera Southern Mallee.
- Numerous climate hazards/variables - Temperature, Maximum Temperature, Minimum Temperature, Mean rainfall, Extreme rainfall (1-in-20 year daily maximum), Solar radiation, Mean wind-speed, Strong wind (99th percentile), Relative humidity, Evapotranspiration, Evaporation, Time in drought, Sea surface temperature (mean).
- Four time periods – 2016-2045 (2030), 2036-2065 (2050), 2056-2086 (2070), 2076-2106 (2090).

It is important to note that the new projections, such as those developed through the Victorian Climate Projections 2019, complement rather than replace or supersede existing projections, as the modelling results all represent plausible futures. Using a range of projections increases the robustness of climate change planning.

Table 2 provides examples of information taken from these projection datasets and set out in a format that is suitable for applying to cost assessments.

Table 2 Examples of climate change projections: a) Greater Melbourne; b) Loddon Campaspe

a) Projected changes to mean rainfall (%) and maximum and minimum temperatures (°C)

Variable/	2030 RCP8.5			2050 RCP8.5			2070 RCP8.5		
Season	Median	Lower	Upper	Median	Lower	Upper	Median	Lower	Upper
Rainfall (%)									
Spring	-14.5	-19.7	-4.1	-19.6	-29.5	14.2	-17.9	-41.5	4.6
Summer	-7.7	-22.0	19.2	-2.4	-13.7	5.2	-0.5	-26.8	11.4
Max temperature (°C)									
Spring	1.4	1.1	1.9	2.4	1.6	3.3	3.3	2.7	4.5
Summer	1.1	0.8	1.9	2.0	1.3	3.2	2.9	2.2	4.5
Min temperature (°C)									
Winter	0.7	0.5	0.8	1.2	1.1	1.4	2.0	1.8	2.3

Source: *CSIRO*

b) Projected changes to 1-in-20 year daily (24 hour) maximum rainfall (%)

	2030 RCP8.5			2050 RCP8.5			2070 RCP8.5		
Season	Median	Lower	Upper	Median	Lower	Upper	Median	Lower	Upper
Annual	**-7.46**	**-21.32**	**3.68**	**-3.5**	**-10.38**	**17**	**5.7**	**-10.74**	**33.64**
Summer	-15.36	-24.30	4.87	-6.75	-17.11	12.70	-6.05	-23.07	32.59
Autumn	4.30	-24.43	42.13	4.93	-17.10	47.19	4.84	-16.41	36.82
Winter	13.32	-15.57	24.30	4.52	-22.23	19.05	3.37	-15.24	41.72
Spring	2.93	-7.16	10.25	1.68	-10.01	9.75	22.64	-12.00	72.53

Source: *CSIRO*

Consistent with the DELWP Guidelines (DELWP 2016), linear interpolation should generally be used to estimate changes to the climate variables for years between the time periods provided. For purposes of sensitivity analysis however (see Step 5), it is also reasonable to introduce a scenario that applies step changes to the relevant climate variables.

Although projections are now provided for an extensive range of climate hazards/variables, in some instances these will still not be available for the climate change impact being assessed, at least not in the exact form required. Three options are available to a water corporation in this situation:

- If data is provided for a climate variable/ hazard that is similar, but not identical to the hazard being assessed (e.g. data is available for extreme 24 hour rainfall, but the hazard of interest is 72 hour rainfall), consideration could be given to whether the available data can be adapted for use in the assessment. CSIRO should be consulted on the validity of this approach before embarking on it[2]. Another useful source of information in relation to extreme rainfall and flooding is the Australian Rainfall and Runoff (ARR) Guidelines (Ball et al. 2019).
- It is possible that projections are available for the hazard in question but, for various reasons, have not been included in the published material. Once again, CSIRO will need to be consulted on whether this is the case.
- An approach could be made to CSIRO or other climate modellers to undertake purpose specific modelling to produce projections for the relevant climate hazard. A water corporation will need to consider whether the time and expense involved in doing this can be justified.

[2] Refer https://www.csiro.au/en/Contact

4. Compile information on impacts and costs

Key points for step 4

- Compiling information on the impacts of climate change and the costs associated with those impacts is likely to be the most resource intensive aspect of the cost assessment
- To successfully complete cost assessment, a water corporation will need to assess the magnitude and frequency of impacts that drive those costs. This will require compiling or generating various data types including exposure data, activity data, capital and operating costs, data on the current climate and climate projections
- Some of this data is typically generated by water corporations as part of their operational procedures. Some of the data will need to be generated through specialised modelling or other analysis.

Compiling information on the impacts of climate change and the costs associated with those impacts is likely to be the most resource intensive aspect of the cost assessment. Unless ''off the shelf'' data is readily at hand (which is unlikely), a significant amount of time will be required to generate the information needed for the assessment.

Table 3 provides an overview of the types and potential sources of information that will need to compiled or generated for a cost assessment. Data generation falls into three main groups:

- analysis of the magnitude and frequency of climate impacts and the data needed to support that analysis including exposure data and activity data;
- capital, operating and other costs; and
- climate data, including current climate and climate projections.

Water corporations generally record or generate relevant exposure and activity data, as well as data relating to capital and operating costs. To be useful to the cost assessment however, this data will often need to be reworked (e.g. involving sorting, reformatting or further analysis).

In many instances, a water corporation will need to undertake specialised modelling or other analysis when applying this data to assess the magnitude and frequency of impacts of climate hazards. Box 3 provides a discussion of some aspects of that analysis.

Table 3 Types and potential sources of information likely to be required for cost assessment

Information/ analysis type	Description	Examples	Likely source(s)	Comment
Exposure data	Assets and services exposed to climate hazards	Storages and headworks, treatment plants, water mains, sewerage mains, waterways	Water corporation records, analysis	Input to impact assessment
Activity data	Activities impacted by climate hazards	Water resources, sewerage overflows, mains bursts, area revegetated	Water corporation records, analysis	Input to impact assessment
Impact assessment	Impact of climate hazards on magnitude or frequency of	Change in water resources (supplied, treated, pumped), change in sewerage overflows, scale	Water corporation records, analysis	Will often require specialist technical analysis/ modelling (see Box 3)

Information/ analysis type	Description	Examples	Likely source(s)	Comment
	activities or assets exposed	and frequency of damage to assets		
Capital and operating costs	Data on costs relevant to the activity or assets impacted	Maintenance costs, cost of capital replacement/ upgrade, water resource costs, treatment or pumping costs	Water corporation records, analysis	Could be reactive or strategic expenditure, short or long run costs
Climate data - current climate	Recent historic data on relevant climate hazards and variables.	Average temperatures, maximum/minimum temperatures, average rainfall, daily rainfall	Bureau of Meteorology (BoM)	Data for BoM weather sites relevant to a number of climate variables are available free online. More specialised data can be purchased from BoM
Climate change projections	Projected changes to climate hazards/ variables with climate change	Average temperatures, maximum/minimum temperatures, average rainfall, daily rainfall, evaporation, time in drought	CSIRO Climate Futures, DELWP 2016, ARR 2019	See Step 3

Box 3: Impact analysis

Modelling and other forms of technical analysis of the impacts of climate change will be required to support many cost assessments. The type of modelling and analysis required will vary depending on the nature of the climate change impact being assessed but could include the following:

- **Water resources modelling** will almost certainly be required to support any cost assessment involving the impacts of climate change on water resources. This type of modelling has been completed by many water corporations in the process of developing their urban water strategies. That modelling has typically assessed the potential for chronic and acute shortfalls in supply under BAU and climate change due to a combination of increased demand (driven by BAU population growth or temperature increases) and reduced supply (driven by reduced average rainfall and runoff and increased frequency and intensity of droughts). Depending on the nature of the costs being assessed, water resources modelling may need to be updated or reconfigured.
- **Hydraulic modelling** may be needed to support assessment of the impacts of increased rainfall intensity on compliance of sewerage or stormwater systems and strategic responses needed to achieve compliance. It may also useful to support assessment of increased rainfall intensity and associated flooding on a water corporation’s assets (e.g. water or sewerage treatment plants).
- **Hydrodynamic modelling** may be useful for a range of cost assessments including, for example, understanding the impact of debris flows following a bushfire in water storages or waterways.

Additionally, a process involving expert scientific or technical judgement, known as **expert elicitation**, can be a useful technique for obtaining information about the probability of an unknown parameter or parameters relating to the impacts of climate change. It is especially useful when quantitative modelling involving probabilistic analysis is not feasible due to a lack of empirical data or where a wide range of climate variables is likely to make the modelling task overly complex. Literature on expert elicitation though, stresses the need for certain principles to be followed (including for example, that uncertainties are quantified) to ensure that the process is as robust as possible (see, for example, Colson and Cooke, 2018).

5. Assess costs

Key points for step 5

- The steps and methods applied to assessing the costs of climate change will vary with each assessment. Nevertheless, there are some common steps to assessing costs
- Where climate hazards are known drivers of particular costs, then year-on-year costs will typically be calculated as average annual damages (AADs), which reflect the scale and probability of one or more climate hazards
- The costs of climate change should generally be calculated and presented as expected values. This involves discounting if future costs
- Sensitivity analysis involving use of different discount rates should be undertaken
- Monte Carlo simulation is a useful technique to quantify ranges of uncertainty

Steps in the process

The steps and methods applied to assessing the costs of climate change will vary with each assessment. However, there are some common elements or steps to assessing costs. These are outlined below, considering two different circumstances.

Circumstance 1: Climate hazards are known drivers of an impact and associated costs[3]

Where a climate hazard (or multiple climate hazards) is the known driver of an impact and associated costs then the main steps in the cost assessment process are likely to be as follows.

1. **Establish the probability of a climate hazard occurring under BAU, for different scales of impact.**

   This process will often need to be supported with specialist technical modelling or, if that is not feasible, expert elicitation. Consideration will need to be given to whether the hazard is ongoing or involves once-off, random events.

- For example, where the focus is on the impacts of reduced rainfall and runoff on water supply, water resources modelling will be needed to assess requirements for additional water from alternative sources, given BAU climate and projected growth in demand. The modelling will need to be undertaken for different periods in the future (e.g. 2030, 2050, 2070). The modelling could include probabilistic analysis, enabling resource requirements to be presented as percentiles.
- If the impacts involve once-off, random events (e.g. floods, bushfires), the technical modelling or elicitation process will be on understanding the average recurrence intervals (ARIs) of hazards of different scales.

2. **Establish a relationship between the probability of a climate hazard occurring under BAU, levels of impact, and cost associated with the different scales of impact**.

   For extreme, random events the relationship between cost and scale of the hazard typically displays a log linear relationship. Thus, provided information is available from at least a small number of discrete events (e.g. records of past events) it is possible to generate a continuous function of the relationship between cost and likelihood of a hazard of a certain scale. This relationship is often presented as an Average Annual Damage (AAD) curve (Figure 7). AADs are calculated as the sum of the cost of each scale of hazard, weighted by the probability of that scale of hazard occurring in a given year. (Thus, AADs for BAU are represented by the area under the BAU curve).

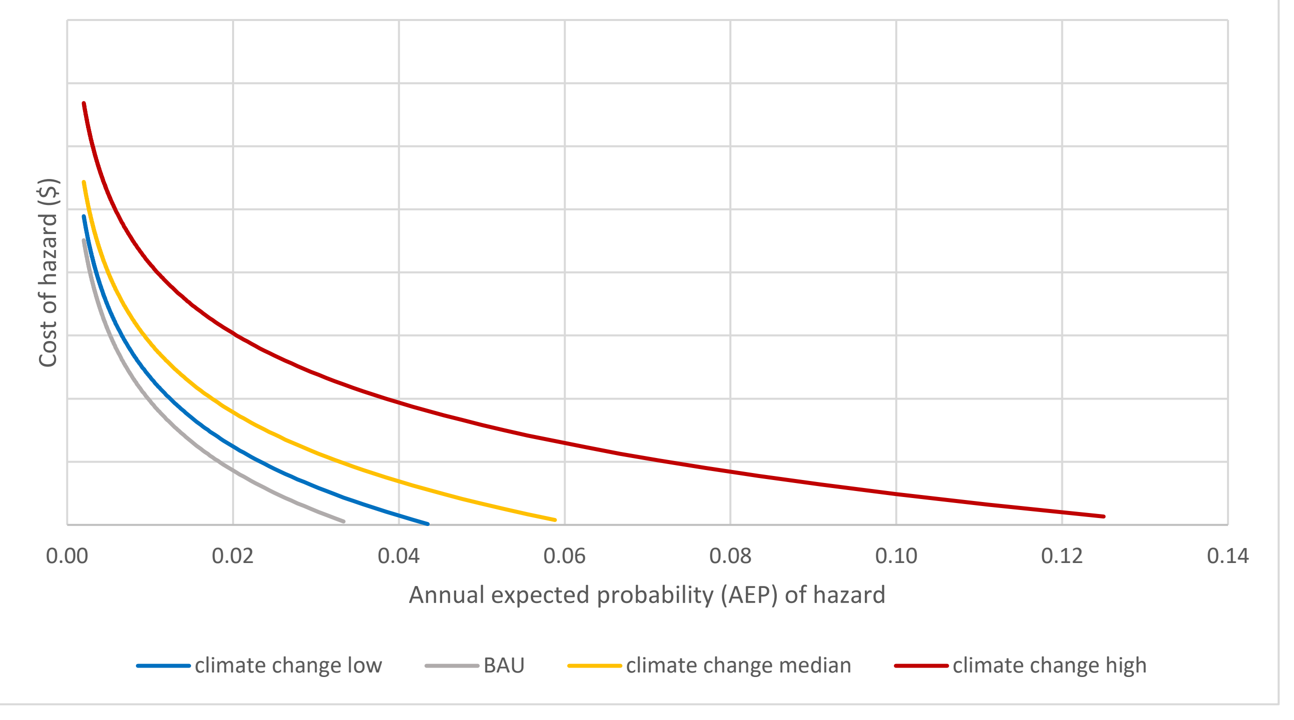
[3] Examples include impacts of reduced rainfall and runoff on water reliability, impacts of bushfires debris, reduced flows or high temperatures on water quality or damages to assets from flooding.

It is important to emphasise that the AADs do not reflect costs incurred year-on-year. Rather, they indicate average annualised costs given total costs that a water corporation could expect to incur over the period of the analysis. In reality, no costs will be incurred in most years, with costs only being incurred in the small number of years that an event occurs.

3. **Assess the change in relationship between the probability of a climate hazard and costs associated with the different scales of impact under climate change.**

   Typically, this will involve re-undertaking steps 1 and 2 with revised probabilities drawing on climate change projections. Outputs will be presented as AADs for different climate change scenarios (Figure 7).

Figure 7: Illustrative example of annual average damage (AAD) curves for different climate scenarios



4. **Calculate expected costs of climate change**

   The costs of climate change should generally be calculated and presented as the expected value of costs (or expected values). Expected values are calculated as the difference between the present value (PV) of AADs under climate change and the present value of AADs under BAU, over a given timeframe (e.g. 10 years, 20 years, 30 years). Present value analysis involves discounting future costs. It is the standard framework used for comparing costs (or avoided costs) over time in financial or economic analysis. There are two reasons for using this approach:

- First, it takes account of a ''time preference value of money'' which individuals and businesses tend to display.
- Second, with respect to the costs of climate change, AADs are not necessary a true reflection of the costs of a climate hazard that can be expected to occur in a given year – in reality costs will be very ''lumpy'', with low or zero costs occurring in most years and much larger costs occurring in a few years. Given this, it is appropriate to present the costs of climate change over a period of time rather than for for single year.

Nevertheless, there is increasing debate about discounting and the appropriate discount rate to use, especially with intergenerational issues such as climate change (see Box 4). For this reason, it is appropriate to present different expected values based on the use of different discount rates.

5. **Estimate ranges of uncertainty around central cost estimates**

   Finally, we note that due to the low and often uncertain probabilities associated with climate hazards and changes to those probabilities under climate change, a statistical technique, such as Monte Carlo simulation, should be applied when calculating expected costs. Use of a technique such as this provides a robust way for the modeller to put ranges of uncertainty (high and low estimates) around the central (mean) estimate of expected costs (see Box 5).

Circumstance 2: Climate hazards are uncertain drivers of an impact and associated costs[4]

Where it is not clear whether a climate hazard (or multiple climate hazards) is the driver of an impact and associated costs then additional steps are required in the cost assessment process.

These steps essentially involve the application of regression analysis to generate estimates of costs over time under BAU and climate. This requires having adequate and consistent historic data relating to the severity of a hazard and the frequency or cost of an impact, to enable a water corporation to quantify the relationship between hazard and the cost. See Box 5.

Note on presentation of outputs

The steps described above apply to assessing the direct financial costs of climate change (i.e. costs to the organisation), as well as the broader economic costs of climate change (i.e. costs to both the organisation and the broader community). If a water corporation believes that it is appropriate to assess the economic costs (because climate change is likely to impact of levels of service for example), then it is important that estimates of the financial costs of climate change and economic costs of climate change are presented separately and that there is no double counting.

[4] Examples include impacts of reduced average rainfall or soil moisture on sewerage overflows or water main bursts. Non-climate drivers such as age and condition of infrastructure could be more important

Box 4: Discounting and discount rates

Discounting is the usual method employed to add and compare costs (or avoided costs) that occur over time. Discounting involves summing across future time periods net costs that have been multiplied by a discount rate, typically greater than zero. If the discount rate is zero, then equivalent costs in each time period are valued equally. If the discount rate is infinite, then only the current period is valued. Thus, the higher the discount rate, the less the value attached to future costs. The rationale behind discounting is that individuals and businesses attach less weight to a cost (or avoided cost) occurred in the future than they do to the same cost incurred now.

In the case of an individual, impatience or 'pure time preference' is the main reason the present is preferred to the future. In the case of a business, since capital is productive, a dollar's worth of investment now will generate more than a dollar's worth of capital in the future. Hence, a business will be willing to pay more than a dollar in the future to acquire a dollar's worth of capital now. The rate at which businesses are willing to discount future capital is referred to as the 'weighted cost of capital' or market discount rate. This is generally higher than the pure time preference rate. A third way to value time preference is the 'social time preference rate' (or social discount rate), which attempts to measure the rate at which welfare for society falls over time. The social discount rate is often linked to the pure time preference rate. An argument against this link, particularly for issues spanning generations, is that public policy should reflect collective interests (including intergenerational equity) rather than private interests.

Where there are no intergenerational issues other than dollars, it is generally appropriate to apply a market discount rate, reflecting the cost of capital. The Victorian Department of Treasury and Finance currently recommends a real discount rate of 7% be applied as the 'standard' rate in cost-benefit and financial analyses. However, since interest rates are currently very low, in historical terms, there is a case for arguing that this rate is too high (see for example, Li and Pizer, 2019). Moreover, when an assessment is undertaken over a long timeframe, involving intergenerational impacts, then society arguably has a 'duty of care' to future generations to consider those intergenerational impacts. In this circumstance, it may also be appropriate to apply a low discount rate to future costs (or avoided costs).

Thus, rigorous consideration of discount rates will be important for the assessment of the costs of climate change. In any case, sensitivity analysis should be undertaken to assess the implications of different discount rates for the assessment.

Box 5: Statistical techniques applied to assessing costs in the context of uncertainty

Assessing the costs of climate change involves substantial uncertainties. Uncertainties stem from:

- Climate related hazards which are, by their nature, random events (e.g. extreme rainfall, droughts, wildfires). Based on empirical evidence, we can apply probabilities to these events occurring in any given year (e.g. ARIs - average recurrence intervals). However, we cannot know with any certainty when they will occur or how often.
- Chronic impacts of climate change. The magnitude of long-term changes to climate averages and the impacts the changes will have are uncertain (e.g. reduced average rainfall on run-off).
- Climate change adds to the uncertainty because the projections themselves are also uncertain.
- Where impacts are the result of multiple climate hazards, uncertainties are compounded.
- Some impacts involving costs to water corporations are the consequence of multiple drivers, climate- and non-climate. Sometimes it is not clear how important the climate drivers are compared to the non-climate drivers.
- Finally, the cost of a particular impact is often also uncertain.

As discussed in *Managing Climate Change Risk: Guidance for Board Members and Executives of Water Corporations and Catchment Management Authorities* (DELWP, 2019), uncertainty is not a justification for inaction. Moreover, tools are available for managing uncertainty. When costing the impacts of climate change, statistical techniques can be used to help manage uncertainties, either by quantifying or reducing levels of uncertainty. Two of the more commonly used techniques, Monte Carlo simulation and regression analysis, are discussed below.

Monte Carlo simulation

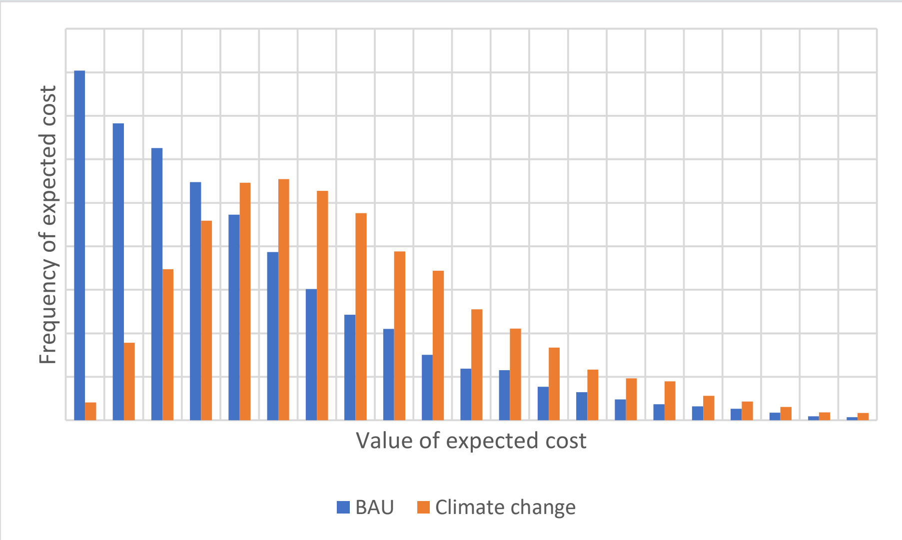
Monte Carlo simulation is a statistical technique used to understand the impact of risk and uncertainty in financial, project management, cost, and other forecasting models. It involves repeated random sampling drawing on parameters specified for one or more input variables used in the calculation of value. When calculating the expected cost of climate change associated with a hazard, for example, if we can specify the mean and standard deviation of the AADs associated with that hazard we can generate a frequency distribution of expected costs based on a large number of random samples (see Taking a step back in the assessment process, it is also feasible to apply Monte Carlo simulation to generate probability distributions of climate hazards under climate change compared to BAU, based on projected changes to means. Low cost Monte Carlo simulation software is now available as an Excel add-on.

Figure 8). In this way feasible lower and upper bounds can be established for the expected costs (e.g. 10 percentile, 90 percentile).

Box 5 continued: Statistical techniques applied to assessing costs in the context of uncertainty

Taking a step back in the assessment process, it is also feasible to apply Monte Carlo simulation to generate probability distributions of climate hazards under climate change compared to BAU, based on projected changes to means. Low cost Monte Carlo simulation software is now available as an Excel add-on.

Figure 8: Illustrative example of output from a Monte Carlo simulation of AADs to generate expected costs



Regression analysis

Regression analysis is a statistical method that allows the relationship between two or more variables to be examined. Unlike simple correlation analysis, regression analysis enables the influence of one or more independent variables (e.g. a climate variable or variables, such as average rainfall or soil moisture) on a dependent variable (e.g. frequency or cost of burst water mains) to be quantified.

6. Next steps

Key points for step 6

- Addressing a series of questions on next steps can assist the water corporation to determine an appropriate course of action following the cost assessment

Assessing the costs of climate change should not be regarded as an end of itself. This will be a process of continual improvement over time to build capacity and ultimately strengthen results.

Once a water corporation has gone through the process of assessing the costs of climate change, for one or more priority issues, it will need to determine what to do with results of the assessment(s) and whether further analysis is required (for example, to reduce uncertainty). Following are a series of questions that a water corporation could pose as a way of determining the steps it should take upon completion of a cost assessment.

- **Question 1:** *Are results of the assessment sufficiently compelling and robust to provide a basis for undertaking further action? (e.g. results of the assessment may provide reasonable order of magnitude estimates of costs but are they a sufficient basis for decision making or at least for starting conversations with line managers about developing adaptation pathways?)?*

  If "yes", go straight to Question 4. If "no", go to Question 2.

- **Question 2:** *Given current results of the assessment is additional work warranted? (e.g. if order of magnitude estimates indicate minimal costs, is additional work justified given competing priorities?).*

  If "yes", go the Question 3.

- **Question 3:** *What additional work is required to improve the assessment. Information, data collation? Technical modelling? Other?*

- **Question 4:** *How should results of the assessment be integrated into the organisation's processes? Do adaptation pathways now need to be considered? Is it important to start engaging regulators or the community about the issue? Or is monitoring of the issue an appropriate response for the time being?*

Finally, it is important to note that even if results of the cost assessment are sufficiently compelling and robust, the assessment is likely to require updating to future as climate projections change or circumstances evolve.

Useful references

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