Guidelines for the Adaptive Management of Wastewater Systems Under Climate Change in Victoria

Final

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VICTORIA State Government | Environment, Land, Water and Planning

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Any questions on these guidelines should be directed to water.climatechange@delwp.vic.gov.au

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.

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Accessibility

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Executive Summary

Assessing the potential impact of climate change on wastewater systems is complex. There are many components that form the wastewater system. And there are many climate-related parameters that affect infrastructure requirements and the ongoing operation of the assets.

These Guidelines support wastewater practitioners assessing the potential effects of climate change on wastewater systems, primarily the direct impacts, those that are likely to impact the systems, as well as the functions and services delivered by wastewater systems. The Guidelines also assist Victoria's water corporations by providing information and guidance to:

- build knowledge of the ways in which the wastewater system may be sensitive to climate change;
- characterise future climate under which the impacts on the wastewater system are assessed;
- assist development of planning in the face of uncertainty;
- assist understanding of when to act and what to act upon; and
- assist development of monitoring programs for further adaptation.

Victoria's water corporations and the wastewater systems that they manage vary in many aspects including but not limited to scale; size; population; age; budget; location; geography; and climate. In recognition of this diversity, the Guidelines propose scalable approaches that can be readily modified to suit business needs.

These Guidelines are based on an adaptive planning framework and use a five-phase cycle of inquiry through which the impacts of climate change on wastewater systems, together with mitigation planning and ongoing review, are explored. The phases and the key messages that they describe are summarised below.

Adaptive Planning Phase	Outcomes provided by the Guidelines
What is happening? *(Section 2 of these Guidelines)*	• The climate is changing, and wastewater systems are vulnerable. • Action is required to be prepared for, and manage the impacts of, this changing climate. • There are multiple legislative obligations requiring water corporations to plan for and manage climate related risks.
What matters most? *(Section 3 of these Guidelines)*	• The substantial climate impacts to wastewater systems which affect a water corporation's ability to deliver against service objectives. • These service objectives must be defined and the risk to achieving them assessed.
What can we do about it? *(Section 4 of these Guidelines)*	• We can identify the adaptations which may be needed for potential future climates. • We can understand the knowledge, values and rules of the interventions which must align for them to proceed.
How can we implement the plan? *(Section 5 of these Guidelines)*	• We can keep the intervention pathways open until decisions must be made. • We can define the system limits, decision points and triggers to enable timely implementation of the plan.
How is it working? *(Section 6 of these Guidelines)*	• We are monitoring the rate of change of the climate and the effectiveness of the interventions already implemented to identify whether the plan is being confirmed or needs to be modified. • We are monitoring the wastewater system limits, decision points and triggers to instigate the next steps of the plan. • We are monitoring the external and internal drivers for adaptation and the development of knowledge relating to wastewater systems, potential interventions, and climate.

Definitions and Abbreviations

The following table outlines key technical terms and abbreviations adopted in this document.

Table 1: Summary of relevant definitions

Term	Definition
Adaptation	Adjustment in natural or human systems that are taken in response to actual or expected climatic [and other] stimuli or their effects, which moderates harm or exploits beneficial opportunities. Adaptation is concerned with managing the unavoidable impacts of climate change (and variability) and considers what needs to be done differently – both more and better – to cope with the change.
Adaptive planning	Adaptive planning is an approach used to address the complexity and uncertainty of the challenges in our rapidly changing future. This process enables decision-making through consideration of possible futures, while allowing for analysis and exploration of the flexibility of various options to meet objectives. Adaptive planning recognises that there are multiple ways to respond to uncertainty and aims to keep as many options open as possible. This enables us to make an informed decision at the right point in time.
Adaptive pathways	An adaptive pathway represents the sequencing of interventions over time. This may be via phases of a single intervention or by the staged or concurrent implementation of several interventions. Multiple adaptive pathways make up an adaptive plan.
Annual Exceedance Probability (AEP)	The probability of a flood event being equalled or exceeded in any year, expressed as a percentage.
Average Recurrence Interval (ARI)	Average Recurrence Interval is the long-term average time interval between events (e.g., rainfall, floods, extreme temperatures) of a particular size or impact being equalled or exceeded.
Climate	A statistical description of “average” weather in terms of the mean and variability of relevant quantities over time scales ranging from months to millennia. It is influenced by factors that operate at various time and spatial scales, including atmospheric energy balance, atmospheric composition and ocean and atmospheric circulation patterns.
Climate change	As per the Climate Change Act 2017 means a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. It is generally challenging to clearly make attributions between these causes. Projections of future climate change generally consider only the influence on climate of anthropogenic increases in greenhouse gases and other human-related factors.
Climate change scaling factors	The percentage or absolute change in rainfall, temperature or other climate variables that may occur from climate change under a given greenhouse gas concentration scenario at an estimated future period in time, as estimated by downscaled outputs from Global Climate Models. Climate change scaling factors typically describe the change relative to a defined reference period.
Climate hazard	The climate change aspect that results in an impact and consequence i.e., high temperature, heavy rainfall, dry conditions as per Table 3.2
Climate impacts	What happens as a result of the climate hazard condition i.e., increased peak sewer flows, mechanical failure, odour generation and emissions as per Table 3.2
Climate reference period	A benchmark period to evaluate the future changes in climate against. The reference period for the IPCC’s Fifth Assessment Report (AR5) is 1986-2005, and the IPCC projections are compared to this period. DELWP’s Guidelines for Assessing the Impact of Climate Change on Water Availability in Victoria recommend reference periods that incorporate an appropriate range in rainfall and runoff variability relevant to assess changes in water availability due to climate change. They also provide scaling factors that estimate the projected change for climate variables (e.g., rainfall, temperature, evaporation) relative to the conditions experienced during the reference period.
Dry weather flow	The combined flow into a sewer from domestic, commercial and industrial sources with no material influence due to wet weather inflows.

Term	Definition
Extreme sea level event	A storm event during which sea levels exceed their typical astronomical tidal variation. They may be caused by storm surges, which are elevated sea level conditions resulting from low atmospheric pressure and wind driven seas and waves or storm tides, which are storm surges which coincide with high astronomical tides.
Fire Danger Rating	Fire Danger Rating is the risk of fire occurring as measured by the Forest Fire Danger Index (FFDI) which is based on a record of dryness of the landscape, rainfall and evaporation, and predicted meteorological conditions for wind speed, temperature and humidity.
General Circulation Model (GCM)	General Circulation Model or Global Climate Model. Computer model that runs mathematical representations of the global climate system. They are used to project the influence of emissions or other global change scenarios on climate. Climate change projections are typically based on an ensemble or group of models rather than the results of an individual GCM.
Hazard	A phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage. Examples of hazards include bushfires, heatwaves, floods
Heat wave	An event with at least two consecutive days of high temperature. High temperature may be based on extreme high temperature maxima (e.g., 35, 40°C or more) or high average daily temperatures (average of daily maximum and minimum temperature).
Intensity Frequency Duration (IFD)	Intensity, Frequency and Duration are quantitative dimensions of rainfall events.
Knowledge, values, rules (KVR) framework	The KVR associated with an intervention option must align so that: • Knowledge: the option is capable of being technically and practically implemented to contribute to the tactical objective(s) with technology/non-technology aspects, costs and benefits (e.g., additional water supply, environmental impact) well understood • Values: the stakeholder/customer/community values are in place so that the intervention option and its outcomes are acceptable if implemented • Rules: the planning, policy, regulatory and governance arrangements are in place to enable the option to be implemented.
Interventions (Options)	Actions that could be undertaken to meet the tactical objectives.
Intervention Limit	The extent to which (quantum) an intervention option can contribute to meeting a tactical objective(s).
Natural Hazards	A "natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage." This definition has been informed by the Hyogo Framework for Action 2005-2015 (United Nations, 2005) and the Sendai Framework for Disaster Risk Reduction 2015-2030 (United Nations, 2015). Examples of natural hazards include bushfires, heatwaves, cyclones, floods, earthquakes and tsunamis.
Operating Condition	Refers to Operating Conditions which impact on performance, a design requirement or capacity assessment of a particular component of the wastewater system. They are used to test the upper and lower range of conditions under which that wastewater system component experiences or operates. For example, Operating Conditions for assessing corrosion and odour in a sewer network require assessment of minimum dry weather flows (to determine maximum corrosion and odour rates at maximum wastewater residence times) and average dry weather flows (to determine average corrosion and odour rates).
Rainfall derived inflow and infiltration (RDII)	Rainfall derived infiltration and inflow is extraneous stormwater and groundwater that enters the wastewater network indirectly because of improper sealing of the pipes and maintenance holes and which results from rainfall impacts on soil moisture content, the groundwater table level and surface run-off.
Representative concentration pathway (RCP)	Representative concentration pathway. A future trajectory for radiative forcing, reflecting changes in atmospheric greenhouse gas concentrations. Four RCP scenarios are commonly presented, ranging from RCP2.6 to RCP8.5. The numeric factor represents the 2100 RF value of the scenario (or in the case of RCP2.6, the peak value).

Term	Definition
Resilience	The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change while continuing to meet functional objectives.
Risk	The potential for realisation of unwanted, adverse consequences; usually based on the consequence and likelihood of an event.
Scenario	A coherent, plausible but often simplified description of a possible future state. Scenarios capture a range of future possibilities and uncertainties and allow decision makers to consider changes whose impacts might otherwise be ignored.
Sewage	Type of wastewater that is produced by a community of people consisting of wastewater discharged from residences and from commercial, institutional and public facilities that exist in the locality.
Sewerage Network	The infrastructure that conveys sewage or surface runoff using sewers.
Strategic Objectives	Strategic Objectives are typically high-level aspirations that often span over a long timeframe. They reflect the longer-term purpose of and direction of what a strategy is trying to achieve (the long-term outcome).
System Deficit	The difference between total projected yield and system demand estimates.
System Limit	A system limit is defined by a tactical objective to be met and is reached when the existing system is no longer capable of meeting it and intervention is required. It can take the form of an external limit imposed which the system must meet (e.g., environmental discharge limit) or an internal limit which reflects the ability of the existing system infrastructure to meet the external limit.
Tactical Objectives (Targets)	Tactical objectives communicate a higher level of detail on how the strategic objective(s) will be met. A tactical objective is a SMART objective and should include a metric and be bound by a timeframe so that the extent to which an intervention contributes to it (the benefit) can be established.
Trigger	A specific criterion identified to begin action to enable a decision to be made to adopt and deliver an intervention so that its benefit (contribution to meeting a tactical objective or system deficit) is available by the time a system limit is reached.
Vulnerability	Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.
Wastewater System	The wastewater system is the system for collection, transfer and treatment of sewage and beneficial use of treated effluent and solids products at a community level operated by water corporations. This includes the physical infrastructure of the sewerage network, sewage pump stations and monitoring sites, sewage treatment plants, recycled water production and distribution, and biosolids management.
Water Demand	The volume of water needed for a particular purpose, which could include residential, non-residential, non-revenue, irrigation, and other purposes.
Yield	Yield estimates are the expected volumes that can be readily supplied from the water supply source over the long term.

Table 2: Summary of relevant abbreviations

Acronym	Description
AEP	Annual Exceedance Probability (see definition above).
AMCV	Asset Management Customer Value
APP	Adaptive pathways planning
AR5	Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).
AR6	Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).
ARF	Areal reduction factor
ARI	Average Recurrence Interval. (See definition above).
AR&R 1987	Australian Rainfall and Runoff 1987
AR&R 2019	Australian Rainfall and Runoff 2019
BAU	Business as usual
BCA	Benefit-cost analysis
BOD	Biological Oxygen Demand
BoM	Australian Bureau of Meteorology
CC scaling	Clausius–Clapeyron scaling
CCIA	Climate Change in Australia web site and technical report; see www.climatechangeinaustralia.gov.au.
CFA	(Victoria's) Country Fire Authority
CH_4	Methane
CO_2*-e*	Carbon dioxide equivalent. As per the Victorian *Climate Change Act 2017*, carbon dioxide equivalent means the standard unit of measurement used in greenhouse gas accounting, representing an amount of a greenhouse gas multiplied by the global warming potential of that gas
COD	Chemical Oxygen Demand
DAPP	Dynamic Adaptive Pathways Planning
DELWP	Department of Environment, Land, Water and Planning
DWF	Dry weather flow
EF	Emission Factor
EPA	Environment Protection Authority Victoria
ERS	Emergency Relief Structure
FMECA	Failure Modes Effects and Criticality Analysis
FOGs	Fats, oil and grease
GCM	General Circulation Model or Global Climate Model (see definition above).
GED	General Environmental Duty
GFDI	Grasslands Fire Danger Index
GHG(s)	Greenhouse gas(s)
GIS	Geospatial information systems
GMSL	Global mean sea level
GRP	Glass reinforced pipe
H_2S	Hydrogen sulphide
IFM	Impacts from rainfall
IPCC	Intergovernmental Panel on Climate Change
KVR	Knowledge, values and rules framework (see definition above
MCA	Multi-criteria assessment
MWF	Medium weather flow
NCCARF	National Climate Change Adaptation Research Facility

Acronym	**Description**
N_2O	Nitrogen oxide
NPV	Net present value
O&C	Odour and corrosion
PCB	Project Control Board
PDWF	Peak dry weather flow
PET	Potential evapotranspiration
RCM	Regional climate models
RCP(s)	Representative concentration pathway(s) (see definition above)
RDII	Rainfall Derived Inflow and Infiltration
RR(s)	Resilience risk(s)
RWTP(s)	Recycled water treatment plant(s)
SEPP (Waters)	State Environment Protection Policy (Waters)
SFARP	So far as reasonably practicable
SoO	Statements of Obligations (for water corporations)
SPI	Standardised Precipitation Index
SPS	Sewage Pump Station
SSP	Shared socio-economic pathways
STP(s)	Sewage Treatment Plant(s)
TCFD	Task Force on Climate-related Financial Disclosures
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
US EPA	United States Environment Protection Authority
VCP19	Victorian Climate Projections 2019
VFCT	Victoria's Future Climate Tool
VicCI	Victorian Climate Initiative
WEF	Water Environment Federation
WSAA	Water Services Association of Australia
WSAAP	Pilot Water Sector Adaptation Action Plan
WWF	Wet weather flow
WWTP(s)	Wastewater Treatment Plant(s)

1. Introduction

1.1 Overview

Victoria's climate is changing. Over this century, Victoria's climate is expected to be characterised by warmer temperatures, changes in rainfall patterns, and more intense storms; with rising atmospheric carbon dioxide and sea levels (DELWP, 2022). Victoria is already experiencing the impacts of climate change and Victoria's climate is expected to continue to change in the future (Bureau of Meteorology & CSIRO, 2018).

Wastewater systems are sensitive to climate conditions and are therefore vulnerable to changes in those conditions. Historically however, Victoria's sewage collection, treatment and disposal systems have been largely designed according to past climate conditions, where climate has been assumed to be stationary for the service life of the asset. With most components of wastewater systems having long operating lives, they will likely be exposed to significant change in climate over those periods. Assumptions of climate stationarity – in essence where a climate is assumed to be static for the assessable time period - in infrastructure planning and design are only appropriate when considering short planning timeframes and assets with very short operational life e.g., less than 20 years.

Extreme weather events such as floods, fires, heatwaves, and droughts have occurred throughout Victoria's history and are already considered in and contribute to many existing design standards and operational practices. Historical planning of these systems has attempted to account for natural climate variability, but climate change is expected to further alter the risk profile around these events and may push current systems beyond the thresholds of acceptable risk; disrupting services, requiring service providers to prematurely repair and replace - increasing costs to customers. The extent and materiality of climate change impacts will vary across wastewater systems and need to be assessed at a local level, using local climate projections.

While many of Victoria's water corporations have begun to build climate resilience into planning, design, construction and operation of their wastewater system assets, specialist sewerage planners have indicated that state-wide climate change guidelines would help them better prepare for climate change.

The *Climate Change Act 2017* requires adaptation action plans be in place for key systems that are vulnerable to the impacts of climate change or essential to ensure Victoria is prepared. The Victorian Government's Pilot Water Sector Adaptation Action Plan (WSAAP) 2017-20 was prepared to support the community and the water sector responsible for water supply, drainage, sewerage, and flood management services in planning for a system that adapts effectively in the face of climate change. The WSAAP also provides a strong foundation for the delivery of Water Cycle Climate Change Adaptation Action Plan for 2022-2026 (WCAAP), the first legislated plan under the Climate Change Act 2017

Action 20 of the WSAAP 2017-20 called for the preparation of Guidelines for assessing the impact of climate change on sewage systems. This document, the Guidelines for the Adaptive Management of Wastewater Systems Under Climate Change in Victoria (the Guidelines), delivers on Action 20 and supports the water sector in implementing elements of the WCAAP 2022-26.

1.2 Guidelines scope and primary audience

The Guidelines have been written to help water corporations identify, assess, and effectively manage or adapt to priority climate change risks. They are intended to complement the Department of Environment, Land, Water and Planning's (DELWP) *Guidelines for Assessing the Impact of Climate Change on Water Availability in Victoria* (DELWP, 2020) (the Water Availability Guidelines) and *Managing Climate Change Risk: Guidance for Board Members and Executives of Water Corporations and Catchment Management Authorities,* and build on various climate science investments made by DELWP (see Figure 1 in Section 1.4).

The Guidelines assist Victoria's water corporations by providing information and guidance to:

- build knowledge of the ways in which the wastewater system may be sensitive to climate change
- identify which elements of the wastewater system to assess further
- apply climate change projections to assess impacts of climate change on elements of the wastewater system
- assist development of planning in the face of uncertainty
- assist understanding of when to act and what to act upon

- assist development of monitoring programs for further adaptation

The Guidelines primarily address the direct impacts of climate on the wastewater system, those that are likely to impact the systems, and functions and services delivered by wastewater systems. They focus on assessing the impacts of climate change on infrastructure design.

The indirect impacts, such as driving an increase in demand for alternative water supplies, are acknowledged as is the potential contribution that the wastewater system can play in addressing these. However, assessment of the indirect impacts is addressed in other guidelines (e.g., the Water Availability Guidelines) or the various water resource management strategies across Victoria, and are not intended to be covered in the Guidelines. Guidance on decarbonisation and the transition towards net-zero greenhouse gas (GHG) emissions, which are not specific to the wastewater system, are also not a focus of the Guidelines.

The Guidelines are intended to serve a broad cross-section of people including water corporation personnel, Board members and technical advisers. However, the content is mainly designed to support wastewater practitioners as they consider the potential effects of climate change on wastewater systems, namely:

- wastewater system planners: working on strategic plans, infrastructure and asset management plans, integrated water management plans and wastewater masterplans
- sewer network modellers
- infrastructure and capital works design and delivery teams
- asset managers
- recycled water and biosolids managers.

The Guidelines propose approaches to the assessment of and responses to climate change impacts that are scalable and/or can be readily modified or adapted to suit business needs based on the extent and materiality of the potential, often complex, impacts. This is regardless of these differences or the level of resources that an individual water corporation can apply.

Water corporations have a wide variety of uncertainties to understand, plan for and manage. The future of GHG emissions, and their effect on the global climate, is uncertain. Population and economic growth, technological change including reliance on fossil fuels, and political and social changes will all have substantial effects on GHG emissions and accumulation in the atmosphere. These factors also pose direct uncertainties on infrastructure design and water corporation operations. Planning for climate change requires an adaptive approach to avoid maladaptation based on any one uncertainty. To aid understanding of the adaptive planning approach and assist water corporations who wish to use this approach, the Guidelines are structured in a way that follows an adaptive planning approach.

1.3 Why are the Guidelines needed?

The Intergovernmental Panel on Climate Change (IPCC) started releasing its *Sixth Assessment Report* (AR6) in 2021. The contribution from Working Group I on the *Physical science basis for climate change* (IPCC, 2021) found that increased concentrations of greenhouse gases (GHGs) in the atmosphere had contributed to warming of the air, land and oceans, changes in precipitation patterns, retreat of glaciers and Arctic Sea ice, sea level rise and the amplification of many weather and climate extremes. It anticipated that global warming of at least 1.5°C above pre-industrial era levels is likely by 2040 under even the most ambitious GHG emissions reduction scenario considered by the IPCC.

The report from Working Group II on *Impacts, adaptation and vulnerability* (IPCC, 2022) found that even with historical levels of warming (1.1°C above pre-industrial levels), climate change impacts on ecosystems, people, settlements, infrastructure and water and food production systems are already pervasive. Continued climate change is projected to amplify these impacts. As the risks increase with every increment of warming, climate change impacts will be strongly influenced by near-term (~2040) actions to reduce GHG emissions and adapt human and natural systems.

Due to the pervasiveness of current and projected impacts of climate change on water, the IPCC considers that water will be critical to future climate resilience responses.

Victorian and Commonwealth legislation (see Section 1.4) holds water corporation boards and executives (and other government business entities) accountable for the identification and management of existing and emerging corporate risks, and their impacts on business performance. It is increasingly clear that climate change poses material risk to water corporations. These are expressed in two main ways:

- **Physical impact risks**: these result from the physical effects of climate change (e.g., increased temperature, sea level rise, etc) on the condition, function and operating life of water corporations' assets and infrastructure, their staff and communities and the natural environments with which they interact.
- **Transitional risks**: transitions towards net-zero emissions challenge business as usual (BAU) and may pose risks due e.g., to requirements to invest in low emissions technologies, increased costs of service provision, changes in regulatory obligations, and altered stakeholder values and social licence.

While the Guidelines primarily focus on physical impact risks from climate change, they also provide insights into transitional risks and their mitigation.

An example of a climate change transition risk for our water sector: Water corporations adapting how they deliver their services as Victoria transitions to a low carbon economy

Victorian water corporations are required to achieve net-zero greenhouse gas emissions no later than 2035 under the Statement of Obligations (Emission Reduction) released in 2022. As such, when a water corporation is considering how, for example, a new wastewater treatment plant should be designed, that water corporation should not only consider design parameters so that plant is resilient under climate change in the future, but it should also consider the energy and emissions profile of that asset:

- How can we design the plant to ensure it is as energy efficient as possible?
- What plant type and design will allow us to minimise direct emissions of methane and nitrous oxides – potent greenhouse gases - from the wastewater treatment process?
- Should the plant be designed to capture the methane released to burn as clean biogas, or can we design in the option of biogas capture in the future?
- Can we utilise oxygen effectively in our wastewater treatment plant process - opening the possibility of co-location with a renewable hydrogen plant in the future?

1.4 These Guidelines in the context of Victoria's legislative, policy and planning framework

Wastewater systems and their management by water corporations sit within a complex legislative, regulatory and policy environment (Figure 1). This framework includes:

Governance:

- *Financial Management Act 2017;*
- *Public Administration Act 2004;*
- *Water Act 1989;*
- *Water Industry Act 1994*;
- Water Corporation Statements of Obligations,

Response to climate change issues:

- *Climate Change Act 2017*

How they interact with air, land, water, and coastal environments:

- *Environment Protection Act 2017*
- *Marine and Coastal Act 2018*.

These legislative and regulatory requirements are interpreted by a suite of policy and strategy documents on climate change, water and environmental management and various guidance documents for the water and wastewater sectors of Victoria's water industry. This is explored further in Section 2.2.

The Guidelines exist to help water corporations satisfy legislative and policy obligations and to implement government policies and strategies in the context of climate change and wastewater systems. They draw on elements of major climate change science investments by both the Victorian and Australian Governments. They also inform how potential interactions between climate change and wastewater systems need to be reflected in water corporations' governance and management processes, as well as their key strategic documents and implementation plans.

The Guidelines seek to provide broad-based support for water corporations as they address climate change in their governance and management of wastewater systems. They do not address every issue in detail.

Victoria's Legislation

- Climate Change Act 2017
- Environment Protection Act 2017
  Environmental Reference Standard
- Environment Protection Regulations 2021
- Marine and Coastal Act 2018

- Financial Management Act 1994
- Public Administration Act 2004
- Water Act 1989
- Water Industry Act 1994
  Statements of Obligations

Victorian policy, strategies and plans

- Water for Victoria

- Marine and Coastal Policy

- Victoria's Climate Change Strategy
- Water Cycle Climate Change Adaptation Action Plan 2022-2026
- Regional Climate Change Adaptation Strategies

DELWP climate science investments

- Victoria's Climate Initiative: 2013-2016
- Victorian Water and Climate Initiative: 2017-2024

- Victoria's Climate Projections 2019
- Victoria's Future Climate Tool

- CoastKit

Australian Government climate science investments

- Climate change in Australia
- Australia Rainfall and Runoff data hub
- CoastAdapt

Water Corporation plans & strategies

- Corporate Plan

- Urban Water Strategy
- Annual Water Outlook

Other strategies and plans which may include:

- Bushfire Mitigation Plan
- Drought Preparedness Plan
- Climate Adaptation/ Resilience Plan/ Strategy
- Melbourne Sewerage Strategy (Melbourne only)
- Sewerage strategies or masterplans
- Asset Management Plans/ Strategies

Relevant guidance

- Guidelines for the adaptive management of wastewater systems under climate change in Victoria

- Guidelines for assessing the impact of climate change on water availability

- Guidelines for development of urban water strategies

- Managing Climate Change Risk, Guidance for Board Members and Executives of Water Corporations and Catchment Management Authorities
- A guide to governing in the water sector

- EPA 168 Guidelines for wastewater irrigation
- EPA 943 Guidelines for environmental managment: biosolids land application
- EPA 1287 Guidlines for risk assessment of wastewater discharges to waterways
- EPA 1322 Licence management
- EPA 1707 Sewerage management guidelines
- EPA 1910 Victorian guideline for water recycling

Figure 1: The Guidelines in the context of Victoria's legislative, policy and planning framework for water resource and wastewater systems and the governance and management of water corporations (Refer to Appendix A.11 for further details)

The Guidelines are a companion to DELWP's *Guidelines for Assessing the Impact of Climate Change on Water Availability in Victoria* (DELWP, 2020) (the Water Availability Guidelines) and *Managing Climate Change Risk: Guidance for Board Members and Executives of Water Corporations and Catchment Management Authorities* (DELWP, 2019). In conjunction with the various reports and data products resulting from Victorian government climate science investments, they provide a comprehensive framework for water corporations to effectively identify, assess, respond to and govern risks associated with extremes of climate and weather and the effects on these of human-induced climate change.

The Water Availability Guidelines provide tailored guidance on how to apply climate science in water resource planning and promote a consistent approach to consider climate change impacts on future water availability. There are clear drivers to have a high level of consistency across the state for water resource planning and as such the use of the Water Availability Guidelines is a requirement on all water corporations through the Minister's Statement of Obligations (Government of Victoria, 2015).

These new Guidelines for wastewater systems are more broadly-based and generally less detailed and prescriptive than the Water Availability Guidelines. The scope of the Guidelines extends to the entire wastewater system and its many and varied exposures to both physical and transitional risks from climate change.

At this stage, and with the Guidelines being the first guidelines acutely specific to climate change adaptation of wastewater systems in Victoria, it is intended that water corporations will make use of, and demonstrate how they have considered the Guidelines, in their wastewater system planning processes.

Victorian legislation, described in Figure 1 above, which provides context for consideration of climate change by water corporations is summarised in Table 3 below.

Table 3: Victoria's legislative context for considering climate change

Legislation	Climate change related considerations
Climate Change Act 2017	• The overarching legislative framework for action in Victoria on climate change. • Requires government to include climate change in decision-making. Section 20 duty requires the government to take account of climate change in all relevant decisions, policies, programs and processes, referring to the policy objectives and guiding principles set out in the Act. • Presents transitional climate risks and opportunities by establishing Victoria's 2050 net-zero emissions target, requiring the development and implementation of State and sectoral climate change adaptation action plans, setting principles for government decision making on climate change, and establishing a system of reporting to provide transparency and accountability on progress on climate change.
Public Administration Act 2004 and Financial Management Act 1994:	• Establishes that boards and executives of public sector organisations, including water corporations, are accountable for identifying and managing existing and emerging corporate risks (of which climate change is one source), and their impacts on business performance.
Water Act 1989, Water Industry Act 1994, and Catchment and Land Protection Act 1994	• Allows the responsible Minister to issue a Statement of Obligation (SoO) that assigns mandatory climate (or other) responsibilities to water corporations. Climate change considerations are stipulated in two of three SoOs to water corporations. • The SoO (General), 2015, requires water corporations to consider climate change in planning and decision-making regarding water supplies. • The SoO (Emission Reduction), 2022, requires water corporations to meet five-yearly emissions reduction targets on the pathway to net-zero and report on progress in annual reports. • The *Water Act 1989* places responsibility on boards of water corporations for strategic planning. The board must ensure that the strategy is informed by the sustainable management principles set out in Section 93 and the entity's business objective. Organisational strategy should address interactions between the organisation's objectives, service delivery and performance expectations and consider risks and opportunities (both physical and transitional) associated with climate change over time. Reflecting Victorian government policy (Water for Victoria; DELWP, 2016) for the sector

Legislation	Climate change related considerations
	to be a leader in climate change response within the state, water corporations are typically further advanced in this process than most other public and private sector organisations.
Environment Protection Act 2017 (EP Act 2017)	• The general environmental duty (GED) is at the centre of the EP Act 2017. It applies to any person who is engaging in an activity that may give rise to risks of harm to human health or the environment from pollution or waste (which includes water corporations with wastewater management responsibilities). A person, such as a water corporation, must minimise those risks, so far as reasonably practicable. The EP Act also establishes a regime of permissions for prescribed activities that may cause harm. Permissions work alongside the GED, ensuring performance standards and conditions are met across a range of activities. There are a number of activities, including wastewater treatment, that require a permission. The GED adds to the complexity of the risk environment faced by water corporations, with that complexity amplified by potential climate change impacts on operation of sewerage networks and wastewater treatment plants.

Victoria's *Water Cycle Adaptation Action Plan 2022-2026* articulates Victorian Government policy on climate resilience for the sector. Each of its five outcome areas (see Figure 2 below) support action by water corporations to understand and address physical impact and transitional climate change risks and build resilience into wastewater systems.

Figure 3: Outcome areas for Victoria's Water Cycle Adaptation Action Plan 2022-2026 (DELWP, Water Cycle Adaptation Action Plan 2022-2026, 2022)

The Environment Protection Act 2017, the GED and EPA publications and guidance relevant to wastewater systems

The EP Act 2017 came into operation on 1 July 2021 and established a new preventive, duties-based framework for the management of risks to human health and the environment (see Figure 4 below). The primary obligation of the EP Act 2017 is the GED. The GED requires that "a person who is engaging in any activity that may give rise to risks of harm to human health or the environment from pollution or waste must minimise those risks so far as reasonably practicable" (SFARP). Of note, the EP Act 2017 definition of waste expressly includes a GHG substance emitted or discharged into the environment. As such the GED applies to emission of GHG substances.

The EP Act 2017 provides that the concept of minimising risks of harm to human health and the environment means a person is required to first eliminate risks of harm SFARP, and if not possible to eliminate those risks to reduce them SFARP.

When determining what is (or was at a particular time) 'reasonably practicable' the EP Act states regard must be had to:

- The likelihood of the risk eventuating
- The degree of harm that would result if the risk eventuated
- What the person (duty holder) knows, or is reasonably expected to know, about the harm, risks, and measures to eliminate and reduce those risks
- The availability and suitability of those measures to eliminate / reduce the risk
- The cost of eliminating or reducing the risk.

Environment Protection Authority Victoria (EPA) refers to the concept of what a person is reasonably expected to know as 'state of knowledge'.

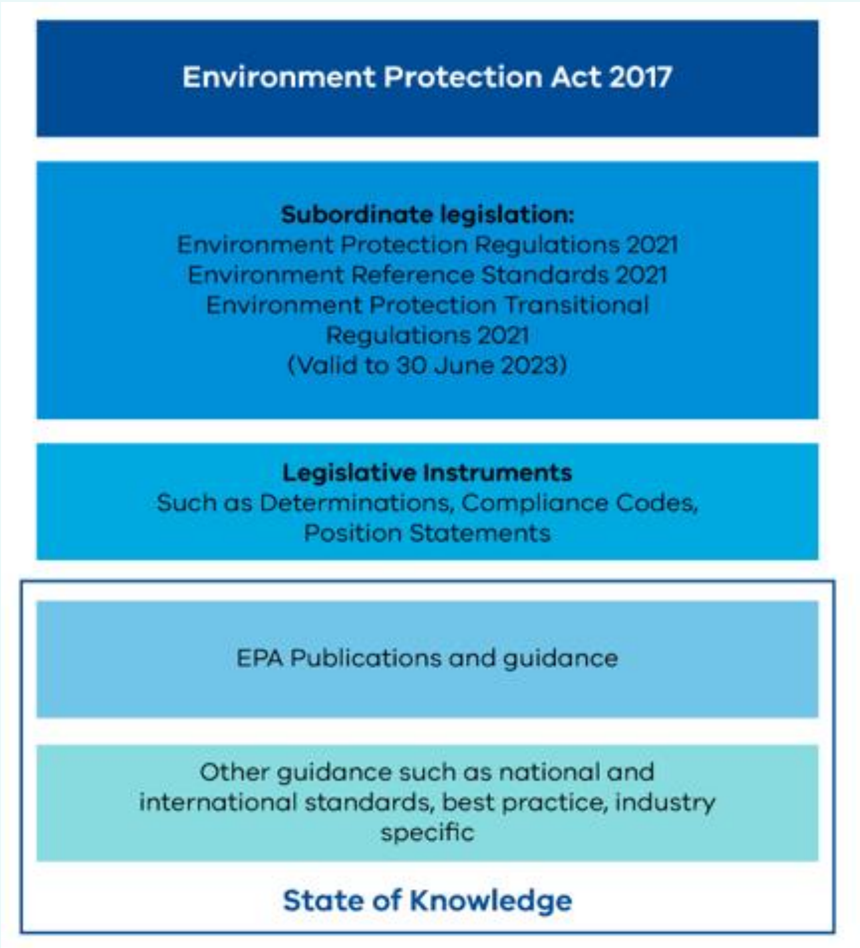


Figure 4: Environment protection framework

The GED strengthens the obligation to manage and maintain wastewater infrastructure beyond minimum compliance requirements, so that the risk of harm is eliminated or minimised SFARP on an ongoing basis. The EP Act 2017 provides that a person who is conducting a business or an undertaking (e.g., a water corporation) contravenes the GED if they fail SFARP to use and maintain systems for identification, assessment and control of risks of harm to human health and the environment from pollution and waste that may arise in connection with the activity, and for the evaluation of the effectiveness of controls. In particular, the GED mandates the use of a risk-based methodology which addresses:

- The identification of risks of harm to human health and/or the environment
- The likelihood / frequency of the risk eventuating
- The consequence / degree of harm that would result from the event
- What the duty holder knows, or is reasonably expected to know, about the harm, risks, and measures to eliminate and reduce the risk
- The availability and suitability of those measures to eliminate / reduce the risk
- The cost of eliminating or reducing the risk.

An example approach for assessing the environmental and health issues from a sewage pump station under the GED framework is included in Appendix A.7.

The onus is on a water corporation to demonstrate that it has undertaken sufficient analysis to demonstrate that the position it proposes meets the GED requirement and the SFARP principle. Water corporations are expected to use EPA publications and guidance together with other industry guidance , such as national and international standards, to inform their understanding of harms, risks and mitigation measures. EPA publications and guidance relevant to wastewater systems include, but is not limited to:

- Environment Reference Standards, EPA (2021)
- EPA Sewerage Management Guidelines, (EPA, 2020)
- EPA Victorian Guidelines for Water Recycling, (EPA, 2021)
- EPA Guidelines for biosolids management, (EPA, 2004)
- State Environment Protection Policy (Waters) (SEPP (Waters)), (EPA, 2018)
- EPA Guideline for Assessing and Minimising Air Pollution, (EPA, 2022)

The above list is not exhaustive, and a range of other guidance is of relevance to wastewater systems including guidance around permissions, risk management and waste duties. At the time of publication, EPA had developed a Draft guideline for managing greenhouse gas emissions which is expected to be published in 2022. The EP Act 2017 also introduces a range of other duties related to contaminated land, waste, pollution and more. A water corporation should be aware of any obligations that may arise under these duties.

Additionally, the EP Act 2017 establishes a tiered permissions framework of licences, permits and registrations as well as exemptions that can be applied for. The Environment Protection Regulations 2021 set out what activities require a permission and detail the type of permission and any applicable thresholds. Permissions may be required to approve development of new or modified facilities and/or operation of an activity. EPA also has a separate obligation under the *Climate Change Act 2017* to consider the impacts of climate change when making a decision relevant to a licence or permit.

There are a number of activities related to wastewater management that trigger permission requirements.

Of note, Part 3.5 of the EP Regulations set out a number of prescribed exemptions from certain permission activities. Depending on the circumstances, these exemptions may apply to activities undertaken by water corporations. EPA also has discretion under the EP Act to modify the effect and coverage of rules or permissions, or exempt persons from the requirement to obtain a permission. Of particular relevance, EPA has issued a determination under the Act which exempts water corporations from the requirement to obtain a development licence for specified modifications to a sewage treatment plant. See EPA determination 02/2021 'EPA Determination – permission exemption for modifications to a sewage treatment plant'.

1.5 How the Guidelines were developed and considerations for future updates

The Guidelines are the culmination of work under Victoria's WSAAP 2017-20 (DELWP, 2018). The work commenced with the preparation of five technical discussion papers considering the effects of climate change on wastewater systems. Following this a scope for the Guidelines was developed in conjunction with the Victorian water corporations.

Assessing the potential impact of climate change on wastewater systems is complex due to the many components that form the wastewater system, and the many climate-related parameters that affect the design and ongoing operation of the assets. The Guidelines build on other existing guidance and climate science literature, analysis processes and data sets as well as assist understanding of how climate change could be considered in planning and management of wastewater systems.

The Guidelines are the first guidelines specific to climate change adaptation of wastewater systems in Victoria and reflect a developing practice which will evolve through implementation. It is anticipated that application of the Guidelines will identify opportunities for their improvement and alignment with developed practice. In line with adaptive management principles, it is expected that these guidelines will be subject to periodic review, evaluation and improvement at intervals deemed appropriate by DELWP, and informed by water corporation practitioners. This could include a review of existing case studies and identification of new case studies to improve and clarify existing guidance. This process will ensure the Guidelines can account for, and respond to, new information and changing circumstances.

1.6 How to use the Guidelines

The materials presented in these Guidelines have been organised around an adaptive planning framework (see Figure 5). Adaptive planning frameworks are essential for effective planning for long–term resilience in response to change and the uncertainty around climate change and climate change impacts. Adaptive planning frameworks are increasingly being used by water corporations in strategic planning for water resource augmentation and major wastewater treatment facilities. The approach complements existing business planning processes. Structuring these Guidelines around an adaptive planning framework is intended as a prompt for water corporations to consider using this approach in wastewater system planning, and to highlight where and how climate change may be considered in the planning cycle. Guidance on the use of adaptive planning is provided in Section 5.

Figure 5: A framework for adaptive planning for responses to climate change and other sources of uncertainty. Adapted from (New Zealand Government, Ministry for the Environment, 2017).

The adaptive planning framework adopted for these Guidelines includes five main phases:

Adaptive Planning Phase	Explanation
1. What is happening? *(Section 2 of these Guidelines)*	This phase seeks to understand the context in which the adaptive plan is being developed and which may unfold over its "life". The analysis seeks to understand the system for which planning is being undertaken and its limits. It also considers existing climate and natural hazard conditions and how these and the operation of the system may be affected by projected climate change (see Section 2 of these Guidelines).
2. What matters most? *(Section 3 of these Guidelines)*	This phase seeks to define the values that will inform planning, objectives and plan implementation. Vulnerability and/or risk assessment, including climate impact assessments, are used to prioritise risks and opportunities that either impede or drive progress towards objectives (see Section 3 of these Guidelines).
3. What can we do about it? *(Section 4 of these Guidelines)*	Interventions that drive progress towards objectives and respond to climate change (and other) risks and opportunities are defined and evaluated in this phase. The knowledge, values and rules (KVR), as well as key triggers and decision points for implementation that need to be aligned before interventions are successfully implemented (see Section 4 of these Guidelines).
4. How can we implement the plan? *(Section 5 of these Guidelines)*	In this phase, groups of interventions are organised into alternative adaptation pathways, which provide flexibility in progressing towards objectives under different climate or other scenarios. Governance processes to support funding and implementation of the adaptive plan. are established. This section of the Guideline addresses approaches to planning climate change responses (see Section 5 of these Guidelines).
5. How is it working? *(Section 6 of these Guidelines)*	Adaptive planning includes a commitment to ongoing monitoring, evaluation and adjustment of interventions. This section of the Guideline addresses monitoring and review requirements in the context of climate change risks and responses (see Section 6 of these Guidelines).

Each phase in the adaptive planning cycle is informed and underpinned by stakeholder engagement.

Figure 6 below provides a guide for wastewater practitioners to the key infrastructure assessment process described within the Guidelines and how this process dovetails with the adaptive planning framework structure of the Guidelines. The guiding questions contained in this Figure are then provided throughout the Guidelines as a quick reference for practitioners following the process.

Practitioners should note that the process in which to characterise future climate hazard conditions largely adopts the process from the Water Availability Guidelines. This is explored further in Section 3.3.2 of these Guidelines. The Water Availability Guidelines steps relevant to assessment of wastewater systems are:

- Create reference period conditions
- Select, understand and work with the climate change scenarios
- Source & apply climate change scaling factors

Where the data provided in the Water Availability Guidelines is relevant to the wastewater system assessment, it can be used. However, data used in wastewater assessments needs to be relevant to the operating conditions to be tested. For example, the Water Availability Guidelines provides annual average rainfall scaling data, but an operating condition adopted for sizing of recycled water storages, the containment and reuse of inflows in wet years, requires consideration of rainfall at a higher temporal resolution.

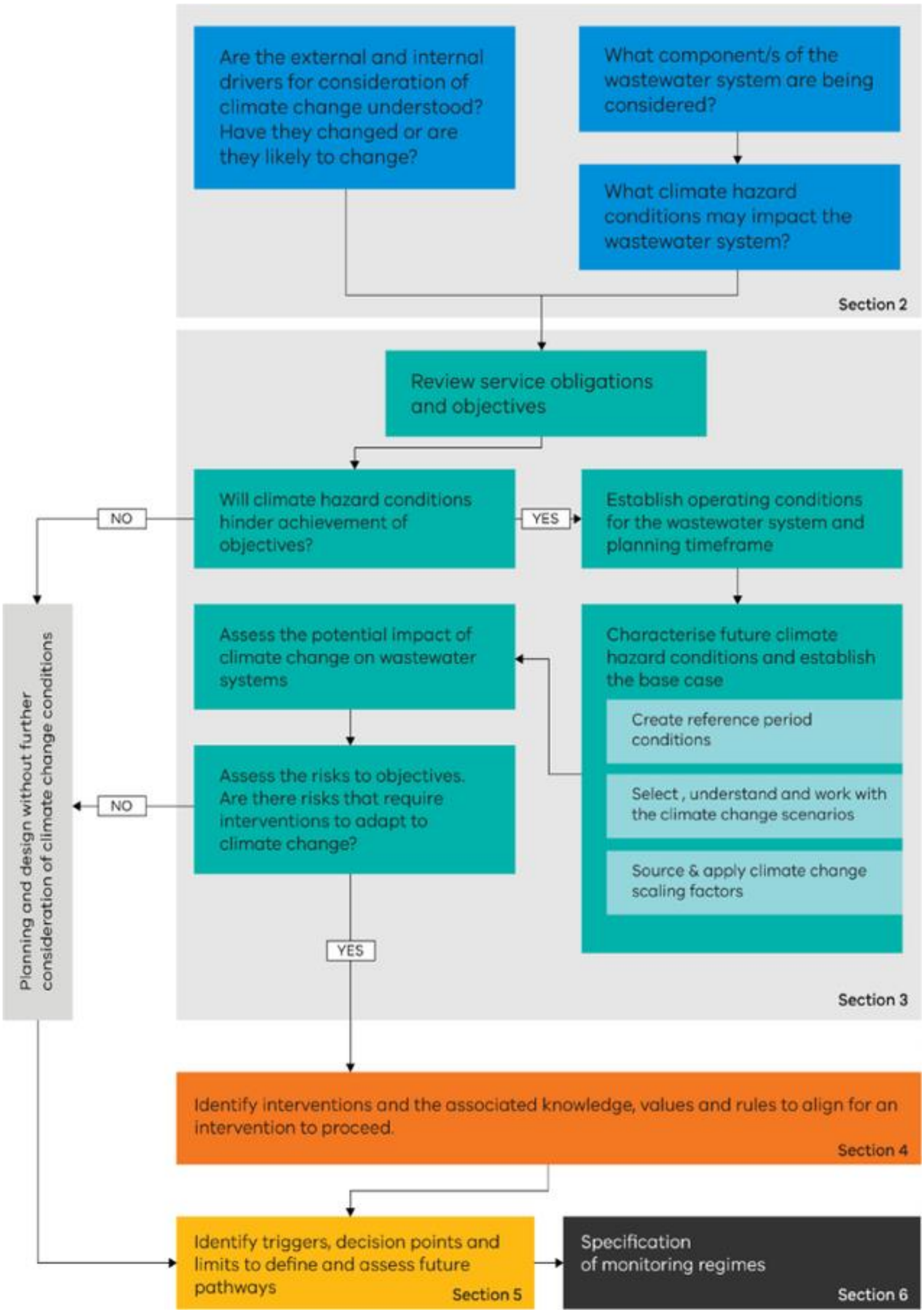


Figure 6: Practitioner's guide to the infrastructure assessment process of the Guidelines

2. What is happening? Establishing the context for managing climate change

SECTION SUMMARY: OUTCOMES PROVIDED BY GUIDELINES SECTION 2

What is happening?

- Our climate is changing, and wastewater systems are vulnerable.
- There are multiple legislative obligations requiring water corporations to plan for and manage climate related risks.
- Action is required to be prepared for and manage the impacts of a changing climate.

The first phase of an adaptive planning cycle seeks to understand the context in which planning is to be undertaken. This phase resembles the initial step in standard risk management processes which water corporations should be familiar with (refer to Figure 7).

This section's main focus is on identifying climate hazards that may pose a risk to wastewater systems and outlining their potential impacts. It describes how climate may change, and provides references for climate science outputs, data and analysis tools that can support assessments of impacts on wastewater systems.

2.1 Wastewater systems considered within the Guidelines

PRACTITIONER'S GUIDE

This section will help you understand and prioritise:

What component/s of the wastewater system are being considered?

Wastewater systems considered in the Guidelines include the physical infrastructure that collects, conveys, and treats sewage and/or trade wastes generated in residential areas and by commercial and industrial facilities. It also includes infrastructure, land and environmental features that are involved in the storage, reuse and/or release to the environment of treated wastes as well as other infrastructure with which it directly or indirectly interacts (e.g., power supply, transportation, stormwater). It also includes the physical, chemical and biological processes of wastewater treatment and management. Table 4 below gives an overview of the main wastewater infrastructure system components considered in this Guideline.

Each of the main components of the wastewater infrastructure system has a unique set of exposures and sensitivities to climate and climate change hazards. Understanding their potential impacts and how these impacts may cascade through the wastewater system is critical to ensuring wastewater systems are planned and designed to be resilient to climate change.

Table 4: Main wastewater infrastructure system components considered in this Guideline

Wastewater infrastructure system component	Description
Sewage transfer networks	Collect sewage and trade wastes from where they are generated and transfer them to wastewater treatment plants. The infrastructure primarily comprises a network of underground pipes and includes access structures and emergency relief discharge locations. The transfer network is typically separated from the stormwater network. other than for designated emergency relief structures (ERSs), i.e., controlled spill locations which usually discharge to watercourses or the marine environment. During some heavy rainfall events, stormwater flows may inadvertently enter the sewerage network (rainfall derived infiltration and inflows (RDII)). Groundwater may also infiltrate the transfer network in coastal and areas with shallow water tables. Some transfer networks use gravity to transfer sewage, and others use pumps.
Sewage pumping stations and network monitoring sites	Sewage pumping stations and network monitoring sites are part of the sewage transfer network. They are identified specifically as they are the primary locations of mechanical and electrical equipment, which potentially makes them more vulnerable to different types of climate hazards than other parts of the transfer network.
Wastewater treatment plants	As the name indicates, these plants treat the wastes they receive to enable safe reuse of water and solids. On occasion treatment products and by-products are released to the environment. Treatment plants may include facilities for storage of treated or untreated wastewater and biosolids. Treatment includes various mechanical, biological and/or chemical processes, some of which may require significant energy inputs. Methane produced in biological treatment processes may be captured and used for electricity generation.
Recycled water production, storage, distribution and use	Following treatment, recycled water may be stored and conveyed for reuse at or away from the treatment plant. It is typically used as a potable or potentially potable water substitute in agricultural or amenity irrigation. The potential end uses are related to both the quality and quantity of the produced recycled water.
Solids management	Solid by-products of differing types, including biosolids, are generated at treatment plants depending on the processes used. Biosolids may be dried and transported elsewhere for reuse as an agricultural soil additive or in energy generation. Other solids products may be used directly off-site.

2.2 Governance, management and planning to consider climate change risk

PRACTITIONER'S GUIDE

This section will help you understand:

Are the external and internal drivers for consideration of climate change understood?

Have they changed or are they likely to change?

2.2.1 Climate risk management

Climate risk management is the process of identifying, evaluating and managing climate risks and opportunities in an organisation. It is a critical role for organisational governance.

Victorian water corporations have a duty to manage the risks posed by climate change and to respond by considering these risks in business decision making. The *Public Administration Act 2004* and the *Financial Management Act 1994* set clear accountabilities for Boards and Executive Management to manage risk when carrying out the functions and obligations that are required of a Water Corporation under the *Water Act 1989* section 95.

The *Victorian Government Risk Management Framework*[1] states that "*effective risk management protects and creates value by enabling informed decision making, setting and achieving objectives and improving performance*". The framework also indicates that integrating risk management into businesses planning, performance management and governance processes ensures efficient financial management and delivery of goods and services.

Risk management processes adopted by Victorian Government for public sector corporations follow AS ISO31000:2018 *Risk management guidelines* (Standards Australia, 2018). The framework (also see Figure 7) includes four interrelated stages in which climate change and potential management interventions should be considered. It is broadly complementary to the adaptive planning cycle used to frame these Guidelines.

- ***Risk context:*** in which the corporation's risk management framework sits, (i.e., the criteria and descriptors used to assess risk consequence and likelihood and the matrix by which risk severity is assessed) the organisation's risk appetite, culture and roles and responsibilities. Scenarios, including climate change scenarios, under which risks are to be assessed are also developed and agreed.
- ***Risk identification****:* both physical impact and transitional risks (and opportunities) arising from climate change (among other risks) are identified under the agreed scenarios.
- ***Risk assessment and evaluation****:* the nature of climate risks and opportunities and their potential impacts on business performance and operation are described and assessed according to the organisation's risk framework. Consequences and likelihood of climate change risks and opportunities are assessed, and overall risk severity is evaluated in the same way as other categories of risk.
- ***Risk treatment****:* interventions and/or processes to eliminate, mitigate, accept or transfer risks and take up opportunities are defined.

Effective risk management also involves stakeholder engagement and communication. Climate risk management should also be adaptive, with regular reviews of the risk context, risk identification and assessments and the interventions to mitigate risk. The climate change risk assessment should also be integrated with the general organisational risk management process

The Victorian Public Sector Commission stipulates that public sector boards should develop and approve a risk management plan suited to the size and needs of their public and risk profile. The board must inform the responsible minister of major risks and the applicable risk management procedures in place to mitigate them".[2] As applicable to an individual water corporation, this would include climate change risks.

Risk can be assessed either qualitatively, where experience and knowledge are essential, or quantitatively, using empirical outputs from analysis of both probability and consequence. A water corporations' corporate risk matrix provides detailed descriptions of how the organisation assigns risk rankings consistently with an overarching risk appetite framework.

Risk management addresses the process through which climate risks and opportunities are identified, evaluated, and managed in an organisation and is critical for organisational governance. In a climate change context, risk is represented as a combination of the probability of occurrence of hazardous event and the impacts of the event. The risk level is influenced by the interaction of vulnerability, exposure, and hazard.

Risk is widely used in developing and prioritising adaptive responses to climate change in infrastructure systems and other features of the built environment. AS 5334-2013, the *Australian Standard for Climate change adaptation for settlements and infrastructure* (Standards Australia, 2013) , characterises risk as the effect of uncertainty on objectives, with the latter potentially having multiple dimensions (e.g., safety, finance, environment, reputation, asset function). This can be reframed in terms of the standard asset management definition of risk as outlined above and in Appendix A.6 The uncertainty of achieving objectives is equivalent to probability of failure and the 'multiple dimensions' is the sum of consequences or impacts when failure occurs (including qualitative and quantitative or monetised assessment of safety, financial, social, environmental and other forms of impact). Risk so characterised equals probability x consequences and then is consistent with the standard approach used for asset management.

[1] Victorian Government Risk Management Framework, 2020, Department of Treasury and Finance, https://www.dtf.vic.gov.au/sites/default/files/document/Victorian%20Government%20Risk%20Management%20Framework%20-%20August%202020.pdf

[2] https://vpsc.vic.gov.au/governance/board-obligations/risk-management/

Figure 7 describes how the main risk management stages (Standards Australia, 2013) and (Standards Australia, 2018) in which climate change and potential management interventions should be considered and how the Guidelines support this.

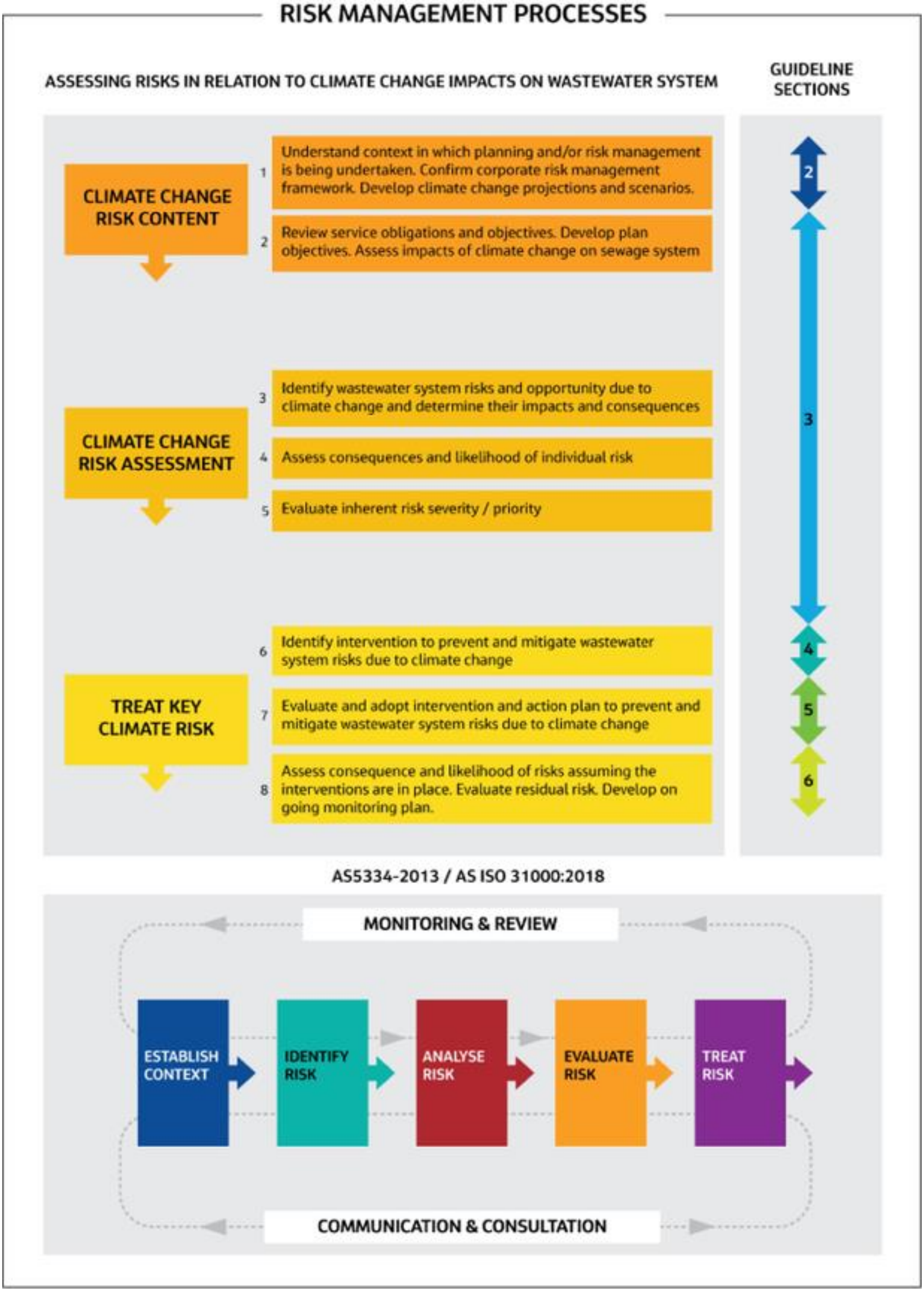


Figure 7: Risk management process, adapted from AS 5334-2013/AS ISO 31000:2018 (bottom) and expanded upon (top).

2.2.2 Climate risk governance

Boards of water corporations are required to consider climate risks (among other categories of risk) under Victorian and Commonwealth legislation. This includes considering complex and uncertain interactions between physical and transitional climate risks, asset systems and services, as well as customer and regulatory expectations.

DELWP (2019) has published guidance on *Managing Climate Change Risk* for the Boards and Executives of water corporations. The guidance seeks to clarify duties of the two groups about climate change risk and how these may be discharged with due diligence. Duties include addressing the implications of climate change through strategic planning and in the management of direct and indirect risk to the corporation's functions. It also addresses governance, strategy, scenario development, risk management and communication.

The *Managing Climate Change Risk Guidelines* are supported by Hutley and Hartford Davis' (2021) legal opinion indicating that Australian company boards and their directors are obliged under the *Corporations Act 2001* to consider climate change risks to their organisation's operations. In their view, board members must consider the foreseeable risks that climate change could pose to organisation's interests and evaluate the organisation's capacity to respond to potential climate change-induced risks. They wrote that "company directors who fail to consider climate change risks now could be found liable for breaching their duty of care and diligence in the future."

Task Force on Climate-related Financial Disclosures

The G20's Financial Stability Board (FSB) established a Task Force on Climate-related Financial Disclosures (TCFD) to develop a framework for the consideration, disclosure and effective governance of climate risks within the finance sector. Since publication of the Task Force's recommendations in 2017, the TCFD framework (see Figure 8 below) has been widely adopted (internationally and across economic sectors) as a model for climate risk governance and disclosure. Climate risk disclosure (broadly) in line with the TCFD framework is mandated by legislation in some jurisdictions (e.g., New Zealand, United Kingdom), but not in Australia.

The Australian Prudential Regulation Authority (APRA) and Reserve Bank have adopted the TCFD framework to disclose climate risks on business operations. Hutley and Hartford Davis (2021) indicated that the TCFD framework a useful tool for addressing climate risk and a potentially appropriate way for Australian corporations and their boards to discharge their climate-risk due diligence obligations.

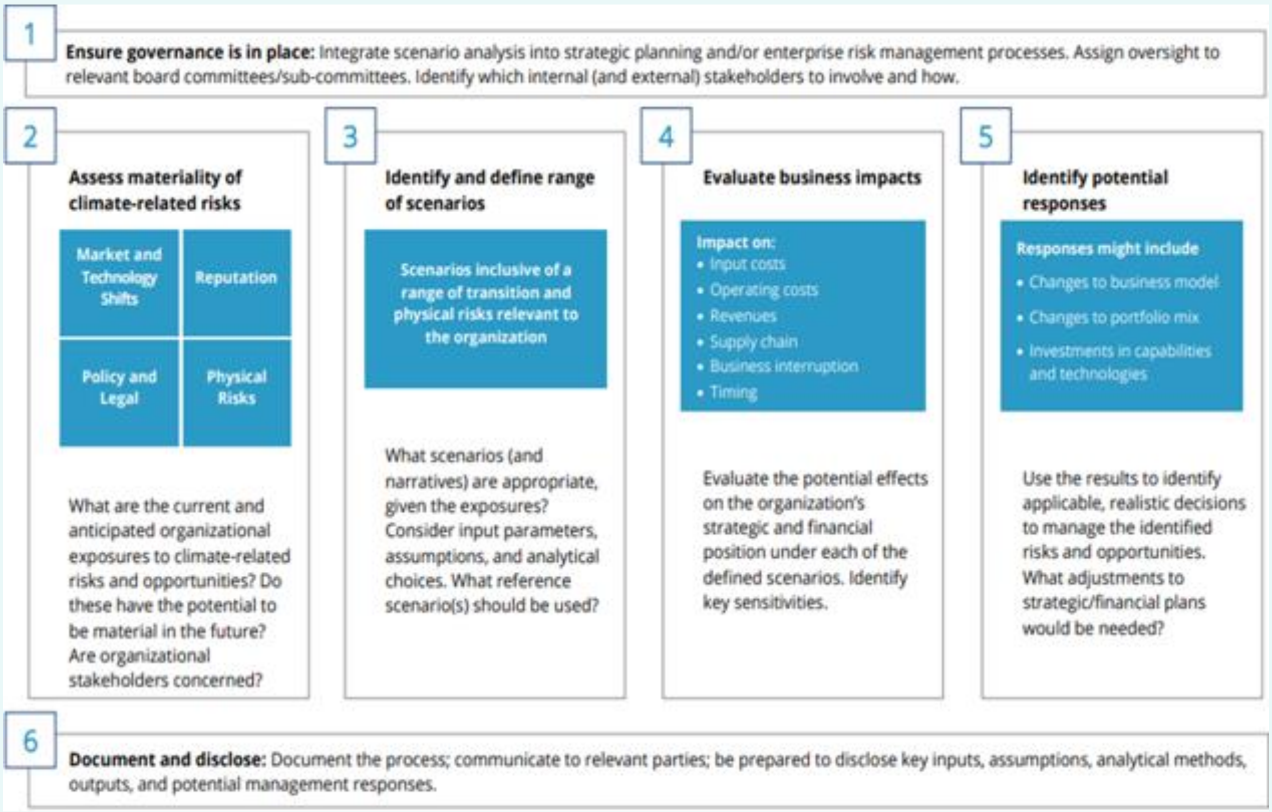


Figure 8: TCFD framework for climate risk governance and disclosure (TCFD, 2017)

Table 5 provides an indication of what the TCFD considers to be climate change risks and opportunities. However, it is noted that these are better characterised as hazards for which risks (probability, consequence, risk aspects) need to be defined and assessed.

Table 5: Typical sources of climate transition hazards to inform risk identification to water corporations (TCFD, 2017)

Hazards	**Potential business impacts**
Legal and policy: *Changes in GHG emissions pricing* *Enhanced emissions-reporting obligations* *Mandates on, and regulation of existing services* *Exposure to litigation due to, for example, not addressing impacts of climate change on sewage spill and its impacts on public health*	Increased operating costs (e.g., higher compliance costs, increased insurance premiums) Write-offs, asset impairment, and early retirement of existing assets and infrastructure due to policy changes
Technological: *Substitution of existing assets and infrastructures with lower energy use and lower emissions options* *Unsuccessful investment in new technologies* *Costs to transition to lower emissions technology*	Write-offs and early retirement of existing assets and infrastructure Research and development (R&D) expenditures in new and alternative technologies Costs to adopt/deploy new practices and processes
Market: *Changing customer behaviour* *Uncertainty in market signals* *Increased cost of raw materials (for construction of assets and infrastructure) and energy (for operation)* *Access to new markets (e.g., recycled water and biosolid use)* *Use of public-sector incentives*	Increased construction and operation costs due to changing input prices (e.g., energy, water) and output requirements (e.g., waste treatment) Re-pricing of assets Increased revenues through access to new and emerging markets (e.g., partnerships with governments, development banks) Increased diversification of financial assets (e.g., green bonds and infrastructure)
Reputation: *Shifts in consumer preferences* *Stigmatization of sector* *Increased stakeholder concern or negative stakeholder feedback*	Undermined reputation due to increased litigious risks Reduced revenue from negative impacts on workforce management and planning (e.g., employee attraction and retention)
Opportunities:	Potential financial impacts
Resource Efficiency: *Use of more efficient equipment and modes of transport* *Use of more efficient constructions, maintenance and operations material and processes* *Use of recycling* *Move to more efficient buildings* *Reduced water usage and consumption*	Reduced operating costs (e.g., through efficiency gains and cost reductions) Increased value of fixed assets (e.g., highly rated energy efficient buildings) Benefits to workforce management and planning (e.g., improved health and safety, employee satisfaction) resulting in lower costs
Energy Source: *Use of lower-emission sources of energy* *Use of supportive policy incentives* *Use of new technologies* *Participation in carbon market* *Shift toward decentralized energy generation*	Reduced operational costs (e.g., through use of lowest cost abatement) Reduced exposure to future fossil fuel price increases Reduced exposure to GHG emissions and therefore less sensitivity to changes in cost of carbon Returns on investment in low-emission technology Increased capital availability

Hazards	Potential business impacts
Products and Services: *Development and/or expansion of low emission operation* *Development of climate adaptation and insurance risk solutions* *Development of new processes and technologies through R&D and innovation* *Ability to diversify business activities* *Shift in consumer preferences*	Increased revenue due to lower operation costs Increased revenue through new solutions to adaptation needs (e.g., insurance risk transfer products and services)
Resilience: *Participation in renewable energy programs and adoption of energy efficiency measures* *Resource substitutes/diversification*	Increased market valuation through resilience planning (e.g., infrastructure, land, buildings) Increased reliability of supply chain and ability to operate under various conditions Increased revenue through new products and services related to ensuring resiliency

2.2.3 Strategic planning

The *Water Act 1989* requires that water corporations undertake strategic planning. Two key strategic documents in which climate change is a key consideration are water corporations' corporate plans and their urban water strategies (Figure 1).

- **Corporate plans:** these need to include a statement of corporate intent that proposes the organisations' vision and mission, business objectives, scope of activities, performance targets, major initiatives and capital projects, and financial forecasts (as per Section 248 of the *Water Act 1989)*. Consideration of physical impact risks and issues associated with the transition towards net-zero emissions is implicit in most key aspects.
- **Urban water strategies:** these are the key planning tool used by water corporations to deliver safe and sustainable water supplies. They identify a mix of actions to ensure the resilient supply of water services over a 50-year planning horizon (DELWP, 2021). Wastewater services and recycled wastewater. are considered within the strategies as part of an integrated water cycle management framework. Climate change implications are to be considered as part of the water supply and demand according to the Water Availability Guidelines.

2.2.4 Service obligations and objectives

Victorian water corporations' service obligations and objectives are founded on compliance with health, environment and economic regulatory requirements and influenced by community expectations and corporate governance. Regulation of risks to human health and the environment from wastewater systems in Victoria is administered by EPA in accordance with the EP Act 2017. Customer and economic regulation are through the Water Industry Act 1994 and the Essential Services Commission (refer Section 1.4).

Figure 9 gives an overview of the hierarchy which informs the development of business objectives; how water corporations plan and implement and measure progress.

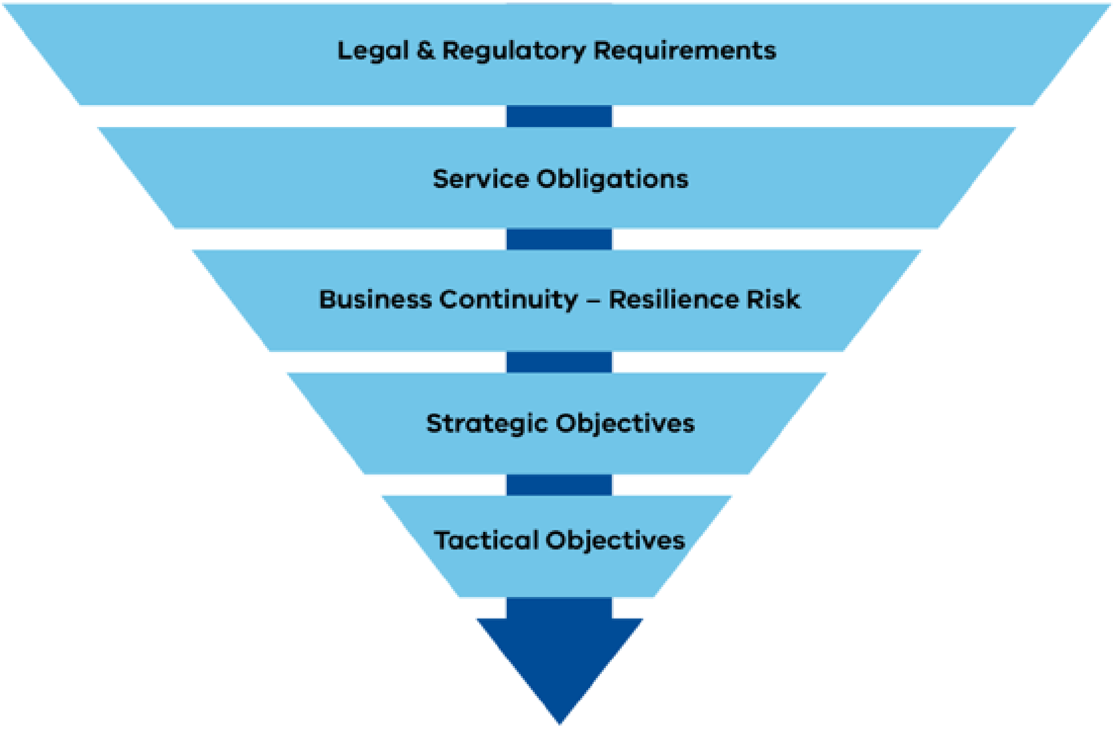


Figure 9: Hierarchy to inform the development of objectives

As can be seen in Figure 9 above, objectives may be categorised as either strategic or tactical. Strategic objectives describe the high-level aspiration or purpose and direction. Tactical objectives communicate a more detailed approach to meeting the strategic objectives. They are often bound by a timeframe and include a metric. Objectives need to be viewed and reviewed within the context of climate change, with consideration of how climate change may impact the likelihood, consequence or nature of harms or outcomes. For example, the ESC sets detailed wastewater system specific objectives in its customer service codes and performance that are monitored through an annual performance report. Water corporations should review existing ESC Pricing Submission wastewater system outcomes and key performance measures to identify how they may be influenced by climate change.

Typical wastewater system objectives that may be at risk due to climate change include for:

- **Dry weather:**
  - Maintain performance of the system in such a way as to avoid chronic (i.e., persistent) leakage. This means providing assurance that asset management practices (including monitoring performance) proactively and adequately manage this aspect of performance as a specifically defined Level of Service.
  - Establish and maintain asset management practices (including those relating to operations and maintenance) which, so far as reasonably practicable, are effective in avoiding acute containment failures (e.g., collapses, blockages, excessive spills, operational failures).
- **Wet weather:**
  - Maintain the capacity of the sewerage system to contain flows associated with at least an 18.1% Annual Exceedance Probability (AEP).
- **All conditions:**
  - Maintain service availability and reliability
  - Prevent structural failures of critical assets

- Customer service obligations are met (including responsiveness, communication, transparency, and affordability)
- Maintain and operate all assets to achieve OHS obligations for public and worker safety
- Establish and maintain operational management practices for all containment failure events that are (so far as reasonably practicable, considering dry and wet weather flows) effective in:
  - minimising impacts where an event occurs.
  - communicating appropriate notifications, instructions, and advice to help minimise impacts on beneficial uses in a timely manner; and
  - timely clean-up and restoration

Additionally, consideration of climate change may drive development of new objectives for water corporations e.g., wastewater treatment plants may need in future to be capable of producing high quality potable water to contribute to meeting shortfalls in available water supply due to increased demands from growth and reduced supply from traditional sources due to climate change.

Appendix A.3 of these Guidelines provides further discussion of the ways in which objectives may be reviewed in consideration of climate change.

2.2.5 Stakeholder and community engagement

Stakeholder and community engagement is relevant at each stage in the planning cycle, but particularly important when establishing the planning context, determining what matters most and in monitoring, review and adjustment. Stakeholder engagement may be informed by climate change, most likely among a wide range of issues and values. Engaging stakeholders and communities in discussions regarding climate change assists in gaining social licence and understanding willingness to pay for interventions or adaptive measures that mitigate GHG emissions or reduce climate risks or vulnerabilities.

2.3 Climate and climate change hazards for wastewater systems

PRACTITIONER'S GUIDE

This section will help practitioners understand:

What climate hazard conditions may impact the wastewater system?

The accumulation of GHGs in the atmosphere since the pre-industrial era have already driven wide-ranging effects on the global climate system. As highlighted by IPCC in their AR6 (IPCC, 2021), these effects include warming of the air, land and oceans, changes in precipitation patterns, retreat of glaciers and Arctic Sea ice, sea level rise and the amplification of many weather and climate extremes. Continued GHG emissions, even under the most optimistic decarbonisation scenarios considered by the IPCC, are anticipated to exacerbate existing effects over the course of this century, and in some cases, beyond.

Victoria's climate has already changed in response to increased atmospheric concentrations of GHGs and this is likely to continue and worsen. Average and extreme high temperatures have increased, rainfall patterns have changed, and sea levels have risen. These effects have already influenced water resource availability (DELWP, 2020) and may also be affecting wastewater system infrastructure and processes. The water sector is continuing to establish and understand relationships between climate conditions and water and wastewater impacts.

The key drivers of Victoria's climate variability and observed and projected future changes in Victoria's climate are described in the Water Availability Guidelines, with supplementary information from other DELWP publications.

This section gives an overview of how climate change impacts could affect wastewater systems. Table 6 provides an overview of the main climate change-related hazards for wastewater systems. Further information on the potential wastewater system impacts is provided in Appendix A.1.

Eight main types of climate change-related hazards have been identified. The first five have the greatest potential for material impacts on wastewater system assets and operations and the last three will most likely have only a minimal impact on those assets.

The climate hazard conditions with the greatest potential impact are based on New Zealand research (Hyghes, Cowper-Heays, Olesson, Bell, & Stroombergen, 2021) with two exceptions. Wind is not considered to have a high potential impact as the average wind speeds are projected to slightly decrease in Victoria (Clarke, et al., 2019) while bushfire is considered to have a higher potential impact as they are projected to continue to become more frequent. Detailed information about how these conditions may change with projected climate change are described in Appendix A.2.

Water corporations should refer to Environment Protection Authority Victoria's (EPA) publications and guidance together with other industry guidance, such as national and international standards, when considering hazards and risks.

Table 6:Summary of future climate hazard conditions and the potential wastewater system response

Climate Hazard Condition	Potential Impact Wastewater Systems
HIGHER POTENTIAL IMPACTS ↓	
Heavy rainfall events: *the atmosphere's capacity to hold water has increased as it has warmed under the influence of GHG emissions. As a result, the intensity and frequency of some heavy rainfall events has already increased. This pattern is projected to continue as the atmosphere continues to warm under climate change. The subsequent stormwater and/or riverine flood risk is expected to increase under certain rainfall and catchment conditions, including in urban environments. In other environments, drier catchment conditions may buffer impacts from increases in rainfall intensity.*	• Higher peak sewer flows due to higher ingress of stormwater and increased groundwater levels and increased risk of untreated sewage spills (albeit somewhat diluted) to the environment may occur. • Flooding that is amplified by climate change may also damage parts of the sewerage network and treatment plant infrastructure.
Increased air, ground, and water temperatures: *increases in average and extreme temperatures may have many effects on wastewater systems.*	• Increased average temperatures in sewers may speed up hydrogen sulphide (H_2S) generation leading to accelerated corrosion in sewers and increased odour generation. • Biological wastewater treatment processes may be enhanced by these changes. • Extreme high temperatures may adversely affect some metal structures, as well as the operation of mechanical and electrical infrastructure. • Grid power supplies may fail because of excessive demand across the network and the derating of transmission and distribution powerlines during heatwaves and at times of extreme high temperature.
Drier climate: *most of Victoria is projected to become drier with climate change, due to reductions in cool season rainfall and increased evaporation. These changes will lead, on average, to drier soils, lower water tables (in some locations) and reduced runoff and streamflow. These trends are projected to occur within the context of Victoria's highly variable rainfall patterns.*	• Drying soils and lower water tables may affect the ground conditions and the structural integrity of parts of the sewer network may be compromised due to cyclic stresses placed on sewers and the joints. • Drier conditions may increase demand for recycled water, but reduce supply, as restrictions are place on residential water users. • Drier soils may worsen the entry of tree roots into sewer pipes, leading to asset damage and greater risk of dry weather sewer spills. A case study investigating the relationship between drier soils and tree root intrusion into sewers is provided below. • Drier soils before some smaller heavy rainfall events may reduce the extent and impact of smaller floods, despite increased rainfall intensity, particularly in catchments that are not highly urbanised. • Lower water tables and drier soils may reduce soil corrosivity and slow the deterioration of sewers at some locations.

Climate Hazard Condition	Potential Impact Wastewater Systems
Sea level rise: *warming of the oceans and loss of glacial ice mass are driving sea level rise. As sea levels rise, they are projected to worsen coastal flooding during storm surges and/or high astronomical tides. Sea level rise may also contribute to rising groundwater levels in some coastal aquifers and to erosion and shoreline retreat in areas with unprotected sandy or muddy coastlines.*	• Without adaptation, all of these hazards are potentially damaging to sewers and wastewater treatment infrastructure located at low elevations in coastal areas. and treatment processes in those plants More elevated tailwater conditions may also affect the design and function of sewer outfalls and emergency sewer overflow or relief structures.
Bushfires: *drier conditions and hotter extreme temperatures may worsen fire weather conditions and increase the incidence and/or intensity of major bushfires.*	• Fires may damage wastewater infrastructure and/or disrupt power supplies and the function of sewer pumping stations and treatment plants and recycled water infrastructure.
LOWER POTENTIAL IMPACTS ↓	
Reduced humidity: *ambient air humidity is projected to decline slightly.*	• Reduced humidity may affect conditions within sewers, and potentially partly offset the effect of increased temperature on sewer corrosion. Alternatively, if humidity was to increase the risk of corrosion (of corrodible assets) would increase.
Elevated carbon dioxide: *elevated atmospheric concentrations of CO_2 drive warming of the climate system but may also have direct effects on wastewater infrastructure.*	• Highly elevated atmospheric CO_2 may accelerate carbonation-related corrosion of some long-lived concrete structures, leading to reduced asset life.
Wind: *climate change may lead to small reductions in average wind speed and either small reductions or increases in extreme wind conditions.*	• Reduction in average wind speed may affect odour dispersion from sewers, sewer vents and maintenance holes and treatment plants. • Changes to extreme wind conditions are projected to be small and unlikely to worsen the risk of wind damage to above ground wastewater infrastructure.

CASE STUDY

Factors that influence sewer blockages **(Marlow, Boulaire, & Beale, 2010)** - *Collaborative investigation between Water Services Association of Australia (WSAA) and member water utilities*

Marlow et al. (2010) indicates a lag period between drought periods and increased pipe blockages. The report, conducted in conjunction with WSAA members across Australia, investigated the various causes of sewer blockages, including the impact of drought.

The standardised precipitation index (SPI) was used to investigate the impact of drought on sewer blockages. The correlation coefficient between SPI and the number of blockages was not significant, though the correlation coefficient for a 4-month lag was determined to be 0.35, which is statistically significant at the 95% confidence level. This supports the inference that blockage rates are influenced by drought.

Amongst other factors, drought periods increase the likelihood that tree roots will grow vertically, to seek water. The study found that approximately 67% of recorded blockages for the metropolitan Melbourne water utility that participated in the study were caused by tree roots.

Another drought-related factor that influences the incidence of sewer blockages, is that intermittent inputs caused by water restrictions reduce localised flow rates and increase solid/sediment retention within sewers. An exploratory analysis found there was relatively strong negative correlation between company-level water consumption and blockages, meaning that lower water usage is linked with higher blockage rates.

3. What matters most? Objectives, future risks, and priorities

SECTION SUMMARY: OUTCOMES PROVIDED BY GUIDELINES SECTION 3

What matters most?

- The substantial impacts of climate change to wastewater systems; those which affect achievement of objectives.
- The objectives must be defined and the risk to achieving them assessed.

What matters most is that water corporations continue to deliver on their commitments to customers, stakeholders, and regulators.

Climate impact assessments consider the potential consequences of climate hazard conditions on wastewater systems. If climate hazard conditions may either impede or drive progress towards objectives for wastewater systems, then a detailed impact assessment may be considered. Potential screening approaches are provided to allow water corporations to identify which climate hazard conditions, infrastructure types, or 'hot-spot' areas, warrant further assessment. The outcomes of the impact assessments can provide the information for a risk assessment which in turn may help identify the interventions needed to manage climate change risks.

Ultimately, the objectives and degree of detail used for the impact and risk assessment is at the discretion of each water corporation.

An overview of the approach offered in this Section to answer the question of 'what matters most' is provided in Figure 6.

3.1 Objective Development

PRACTITIONER'S GUIDE

This section will help you:

Review service obligations and objectives.

A resilient wastewater system for Victoria would be one that is prepared for, able to withstand and then recover and learn from disruptive trends or events and continually adapt going forward.

When reviewing objectives in the context of climate change it is important to consider all levels of the hierarchy of an organisation's objectives (refer Section 1.4) including reviewing regulatory requirements, service obligations, business resilience and strategic and tactical objectives.

A review of service obligations (customer charter, economic and environmental regulatory) in the context of climate change may lead to revision or development of new objectives. Refer to Appendix A.3 for additional guidance on customer and economics considerations.

A more transformational, resilience-based approach should be considered in development of objectives to address risks to the wastewater system and to deliver on a water corporation's vision. A resilient wastewater system is prepared for, able to withstand and then recover and learn from disruptive trends or events. Objectives should consider what may happen if the wastewater system is not resilient and be developed to describe the desired outcome. Examples are provided in Table 7.

Table 7: Example resilience risks and objectives

What may happen if the wastewater system is not resilient	Objective
Cost shocks to both water corporations and customers	Ensure that responses to all service obligations impacted by climate change and the associated investment and benefits meet PREMO principles and are explicitly agreed to by customers and are prudent and cost efficient.
Infrastructure investment regrets (under or over investment)	Ensure that monitoring plans are in place to establish the effect of climate change (extent, rate of change) on all relevant service objectives. Matched with this, we need to ensure that sufficient time is embedded in planning processes to identify triggers when system limits are imminent and allow sufficient time for analysis for choice of intervention, decision making, and delivery to ensure cost efficient infrastructure investments are made.
Lack of suitable land for critical infrastructure	Ensure that there is a sufficient buffer zone around wastewater treatment plant assets and essential services (e.g., power supply) to manage potential bushfire risk without service interruption; and/or that wastewater system assets are located on land unaffected by predicted sea level rise, groundwater, and flooding impacts due to climate change.
Opportunity lost for recycled water resource utilisation	Ensure that wastewater treatment plants are developed to provide a capability to contribute to water resource management consistent with the relevant water strategy(s), in terms of product quality, timing and quantum.

All service obligations potentially impacted by climate change, including customer service, compliance, asset management, business risk management and customer negotiated objectives and obligations should be considered.

When addressing resilience risks the particular aspect of resilience being impacted by climate change and considered should be defined and both an associated measure of performance and a quantitative target (i.e., tactical objective) for it specified. For example, this could specify the expected acceptable variability in system performance given climate change impacts.

It is preferable to reframe existing strategic and tactical objectives associated with wastewater systems that relate to, or are impacted by, climate change, rather than writing new ones. Table 8 gives specific guidance for how objectives could be developed and reframed.

Table 8: Guidance for development of strategic and tactical objectives in response to managing the impacts of climate change on wastewater systems

Step	Guidance	Example Objectives
1	Review existing corporate strategic objectives and identify those sensitive to climate change impacts.	Ensure safe, secure, reliable and affordable water and sewerage services that meet society's long-term needs (this includes identifying action to adapt to climate change)
2	Review wastewater service and all other operational tactical objectives and identify those sensitive to climate change impacts. This should also include a review of any performance targets associated with objectives. Define linkage between the business strategic and tactical objectives.	Review and update the wastewater systems capacity modelling including an RCP8.5 (and RCP4.5 if required) climate scenario to assess the need for any augmentation or upgrade with priority given to networks in growth areas and/or where there is uncertainty about the capacity of the network to manage the future impacts of climate change.

Step	Guidance	Example Objectives
3	Develop quantifiable tactical objectives as required to achieve strategic objectives defined in Step 1.	*Tactical objectives with specific climate change considerations, namely based on climate change conditions for an RCP8.5 (and RCP4.5) climate scenario include:* • Ensure sufficient transfer system and network capacity is provided to meet all servicing strategy targets in the required timeframe • Net-zero GHG emissions from wastewater services by 2030 and beyond. • Ensure all customer contractual obligations for recycled water re-use are met *Tactical objectives sensitive to climate change include:* • ≤X sewer blockages per 100km of sewer main per year • Dry Weather Overflows: − ≤ X Dry Weather Overflows per 100km of sewer main per year; and/or − ≤ X Dry Weather Overflows and ≤Y volume (ML) per year • Wet Weather Overflows: − ≤ X Wet Weather Overflows per 100km of main per year; and/or − ≤ X Weather Overflows number and ≤Y volume (ML) per year • No repeat sewage overflows for individual customers per year • No fugitive odours from sewerage system/network • Zero sewage overflows affecting sensitive waterways • Asset management − No structural failure of critical assets or assets in critical locations − No assets in an extreme risk category − No more than Y structural failures per year on non-critical sewer network assets • 100% of WWTP effluent is fully compliant with licence.

3.2 High level scanning for climate impacts

PRACTITIONER'S GUIDE

This section will help you understand:

Will climate hazard conditions hinder achievement of objectives (to address wastewater system climate change risks prepared)?

Two scanning approaches are outlined in the following sections, firstly, a high level 'Climate Change Impact Scanning Approach' which can be undertaken as a first pass desktop study by a water corporation based on a high-level understanding of climate change impacts and the components, location and condition of their wastewater treatment system assets. The impacts identified from a simplified scanning approach can be used to inform the focus of and level of detailed required in further impact assessments as described in Section 3.3.

The second scanning approach, 'Climate Change Vulnerability' assessments are a more detailed assessment and are used to identify 'hot spots' that then become the focus of a more detailed impact and risk assessment and to inform adaptive responses. For example, this approach could be useful where simplified empirical equations are available to readily establish the impact of climate change conditions as can be undertaken for high level assessment of corrosion and odour impacts in sewers.

3.2.1 Simplified Scanning Approach

A simplified climate change impact scanning approach may be used to guide decision makers on the need for detailed impact and risk assessments. These scans should preferably be undertaken by a team and certainly involve experienced wastewater practitioners and operators for best outcomes.

There are two tiers of high-level scans that could be undertaken. One based on the objectives impacted and the second on the assets (or components of the wastewater system impacted by climate change.

The first tier of scan would develop criteria based on objectives alone (refer to Table 9). While the second tier would consider the combinations of each wastewater system, and/or the components within it, and the climate hazard conditions (refer to Table 10).

Qualitative assessments of the risks can be made using the water corporations corporate risk matrix which typically provides detailed descriptions of how the organisation assigns risk rankings and uses a traffic light system to rank or prioritise them for more detailed assessment. Priority infrastructure / climate hazard condition combinations could be identified to understand areas of focus for detailed impact assessments based on risk.

Table 9: Climate change impact scanning criteria - sample

Criteria	Low	Medium	High
Potential impacts to the wastewater infrastructure due to climate hazard conditions that hinder achieving the objectives (noting that the full list of objectives / obligations could be named for consideration)			
Potential impact to the customer charter obligations due to climate change impacts on the wastewater system			

Developing multiple criteria will highlight which climate hazard conditions and infrastructure combinations present the highest risk to the water corporations' objectives. Using the first criterion in Table 9 and an understanding of the infrastructure and typical climate change impacts outlined in Table 6 and Appendix A.1, a second tier scan/simplified climate change impact assessment can be undertaken. A hypothetical outcome of the scanning approach is shown in Table 10. This example identifies key areas of focus for a detailed impact assessment could be heavy rainfall on the sewerage network, SPSs, WWTPs, biosolids management and recycled water storage infrastructure.

Table 10: Climate change impact scanning approach - hypothetical outcome

Wastewater System Component	Climate Hazard Conditions							
	Heavy rainfall	Tempera-ture extreme	Drier Climate	Sea Level Rise	Bushfire weather	Carbon dioxide	Relative Humidity	Wind speed
Sewerage network								
SPS's and network monitoring sites								
WWTPs								
RWTPs								
Biosolids Treatment								
Recycled water storage								

3.2.2 Vulnerability Scanning Approach

Vulnerability assessments can also be used as a scanning tool before detailed impact and risk assessments are carried out. They are used to identify “hot spots” – locations or types of system features – that then become the focus of more detailed impact and risk assessments and to inform decision making.

The IPCC’s *AR6* (IPCC, 2022) describes vulnerability as, “the propensity or predisposition to be adversely affected” including “sensitivity or susceptibility to harm and lack of capacity to cope and adapt”. Vulnerability is a function of the nature and extent of the change to which a system is exposed, its sensitivity, and its adaptive capacity. The concept is illustrated in Figure 10.

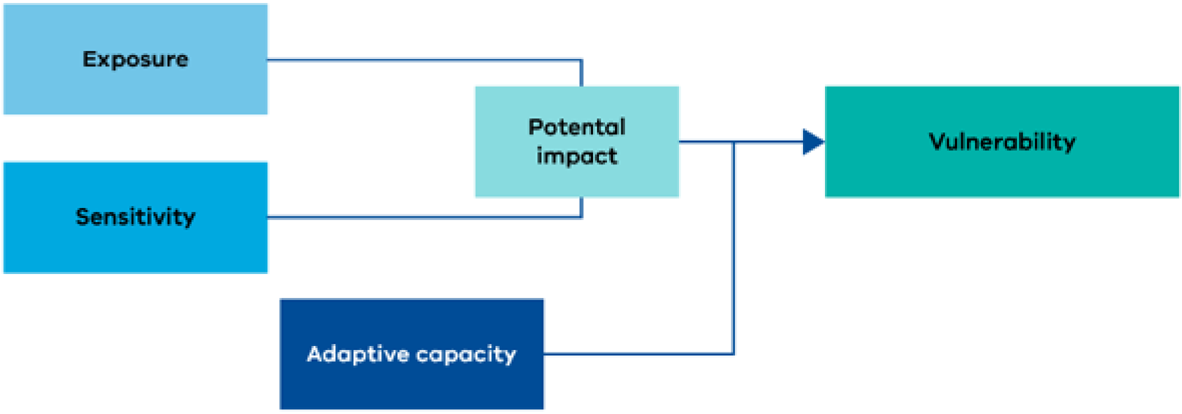


Figure 10: Schematic describing the concept of vulnerability

Framing Figure 10 in the context of climate change impacts on wastewater systems exposure, sensitivity and adaptive capacity is defined as follows:

- **Exposure:** extent to which a “system” (wastewater system, i.e., wastewater network, SPS, STPs etc.) experiences and/or is projected to experience climate-related hazard events that may damage or disrupt system functions and service provision.
- **Sensitivity:** extent to which exposure to climate-related hazards is likely to result in harm, damage or disruption to the wastewater system, this could be considered by component or asset type.
- **Adaptive capacity:** extent to which the system can anticipate, resist, and adjust to climate change impacts. One way to assess this would be to establish what limiting magnitude of climate change impact would be accommodated within the system and still remain within acceptable performance on objective(s). Alternatively, resilience objectives with targets could be specified and performance against them assessed for varying extent of climate change impacts.

A vulnerability assessment involves identifying and assessing criteria that represent each of these three attributes for the system of interest and are used to assess the direct and indirect (e.g., supply chain) impacts from climate change on system components water corporations could consider.

The vulnerability assessment may be delivered in a simple numerical format or represented spatially (see Figure 11).

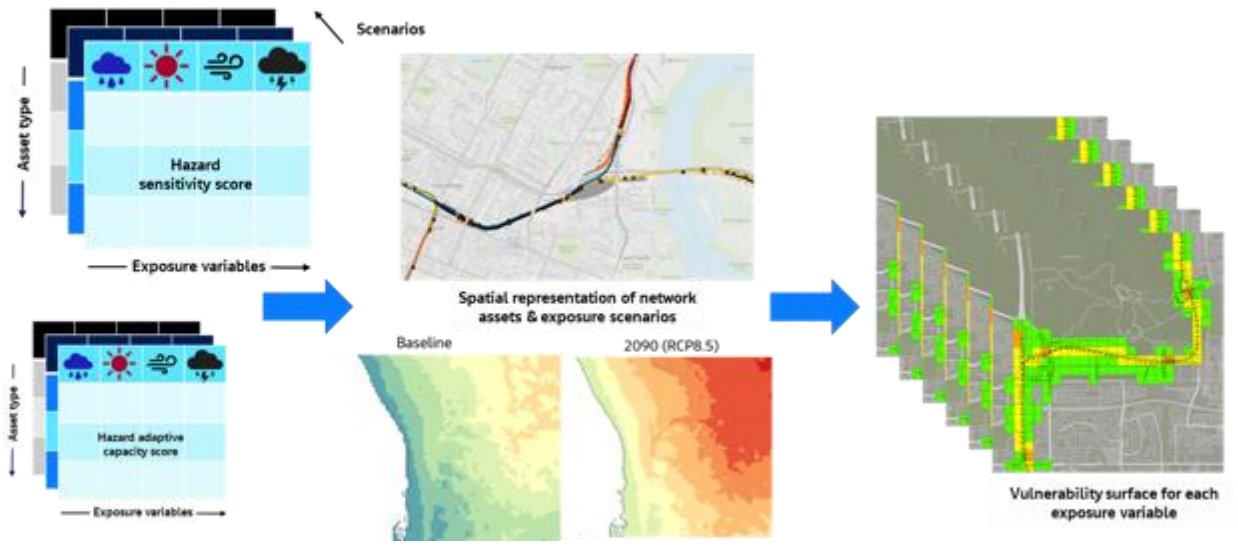


Figure 11: Vulnerability of linear assets to climate change, 2030 and 2090, RCP8.5

Spatial vulnerability assessments use Geospatial information system (GIS) data overlayed with data from climate projections to identify hotspots of climate vulnerability across linear infrastructure such as wastewater networks i.e., high hazard exposure/exposure to multiple hazards and assets/activities that are relatively sensitive to the hazards. A detailed impact assessment and risk assessment could be considered for an identified hot spot to understand the specific implications of climate hazard conditions on sensitive assets/operations.

3.3 Detailed Impact Assessments

PRACTITIONER'S GUIDE

This section will help you:

- establish operating conditions for the wastewater system and planning timeframe,
- characterise future climate hazard conditions and establish the base case,

  Creating reference period conditions, selecting, understanding and working with the climate change scenarios, and sourcing and applying climate change scaling factors
- and assess the potential impact of climate change on wastewater systems.

Assessing the potential impact of climate change on wastewater systems is complex due to the many components that form the wastewater system, and the many climate-related parameters that can affect the design and ongoing operation of the assets. Key complexities include:

- multiple interconnected components (e.g., transfer network, treatment plant, pumping stations) within the wastewater system that may be impacted by multiple climate hazards
- different components are associated with different types of impacts (e.g., pipe failure, ingress or egress to sewer, odour risk, failure of assets).
- causal links in the process whereby climate impacts wastewater systems are complex (e.g., corrosion, root ingress, flooding).
- climate extremes or climate variability, which are causes of potential impacts are often difficult to project, e.g., impacts may occur at a sub-daily timestep which is often not considered when changes are presented as annual averages.

- assessment tools vary based on both the wastewater system components and type of impacts to be assessed.
- uncertainties and assumptions required for future wastewater system design. Just as climate is not stationary, neither are many other contributing assumptions for infrastructure planning such as population, regulatory obligations (e.g., DWF spills targets, GHG and energy neutrality targets), and the wastewater system's role in a circular economy.

A holistic approach is recommended for assessing the impacts of climate change to wastewater systems. An example approach is illustrated in Figure 12. This approach provides:

- an assessment approach for a large system which is often considered/designed/reviewed in smaller, separate, parts (e.g., the catchment network and wastewater treatment plant), allowing for the large system to be assessed as it would be typically
- a consistent basis of assessment for the separate parts of the system with the planning period and climatic reference period selected at the commencement of the study,
- a consistent basis of assessment for the climate change impacts (rainfall, temperature increases etc.)
- consistent inputs and outputs for the assessments (for example flow projections), where the output of one assessment (e.g., sewer network) is the input to another assessment (e.g., treatment plant assessment).

Each assessment method illustrated in Figure 12, represents a sub-section offered within this section of the Guidelines.

Water corporations should note that the EPA is required, when making a licence or permit decision, to consider impacts of climate change. Logically, this means applicants will need to provide sufficient information to EPA on the impacts of climate change to the proposed activity (e.g., an A03 sewage plant). The detailed impact assessment approach offered here by the Guidelines may therefore also be relevant when applying to EPA for new or amended permissions.

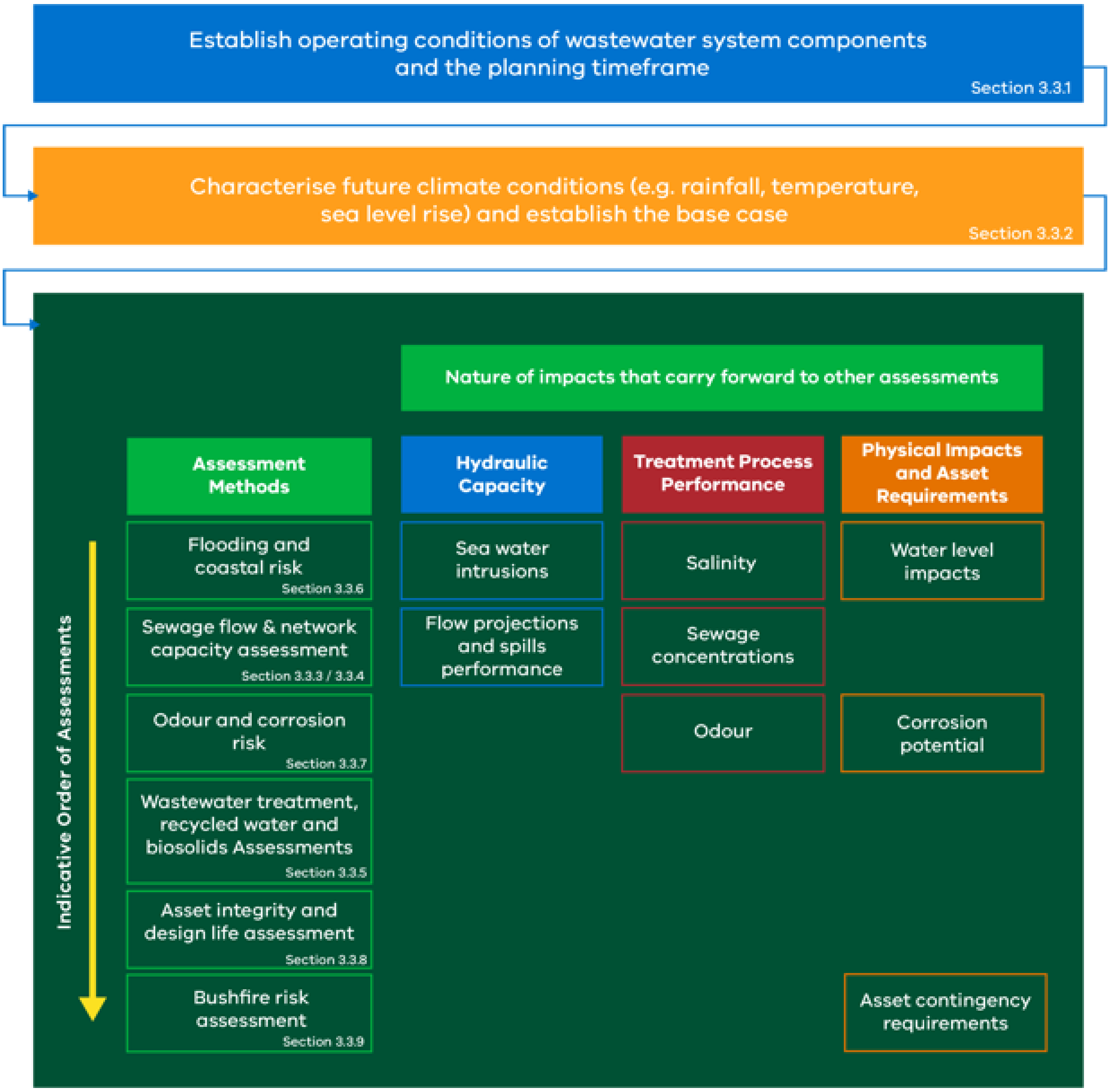


Figure 12: Climate change impacts assessment – wastewater system aspects - example holistic approach

In determining the order for assessments, water corporations should consider the required information for the subsequent assessment(s). A water corporation may elect to undertake a climate risk assessment in a different order, adopting assumed outputs from relevant earlier assessment (based on previous studies if available) and updating the assessment in the future as more information is available. Further detail on the steps is provided in the following sub-sections of the Guidelines.

3.3.1 Establish operating conditions and planning timeframe

In order to assess the impacts of climate change, the operating conditions and planning timeframe for assessment must be defined. This step seeks to establish the nature and scale of the engineering inputs which will be used to demonstrate the potential impacts of climate change to characterise the climate data inputs (e.g., the impact on treatment equipment sizing to treat peak wet weather flows requires heavy rainfall data at an hourly timestep).

Operating conditions are linked to objectives and are used to demonstrate the conditions which the wastewater system must be resilient to. They typically define the lower and upper bounds of the system operation.

The planning timeframe is at the discretion of the water corporation and may align with other plans and strategies such as the Urban Water Strategy or the asset life for the wastewater system component to be considered. A minimum of 35 years is recommended or in longer term visionary strategies up to 50 years from current.

These operating conditions should then be tested under a base case assessment i.e., using the climate design data normally used by the water corporation and for the climate scenarios at the planning timeframe/s defined.

The operating conditions will depend on the wastewater system component, or treatment process and other water corporation or industry design requirements. For example, operating conditions could be:

- peak wet weather flow conditions to determine peak network and treatment requirements
- dry weather flow conditions to understand minimum conditions
- a 'Wet' year to understand the impact of wet year conditions on recycled water demands/storage and sludge drying pans
- an 'Average' year to understand average conditions and
- a 'drought' year to understand the impact of drought year conditions.

Selection of the rainfall and evaporation percentile conditions, e.g., 90^{th}%ile or 95th%ile for a 'Wet' year, and 10^{th}%ile or 5^{th}%ile, for assessing the performance of relevant assets under climate change can be at the discretion of the water corporation, consistent with their regulatory requirements, design standards or contractual requirements (e.g., for supply of recycled water). However, these need to be consistently applied across the various assessments.

3.3.2 Characterise future climate conditions and define the base case

Practitioners should note that the process in which to characterise future climate hazard conditions largely adopts the process from the Water Availability Guidelines. The Water Availability Guidelines steps relevant to assessment of wastewater systems are:

- Create reference period conditions
- Select, understand and work with the climate change scenarios
- Source & apply climate change scaling factors

Where the data provided in the Water Availability Guidelines is relevant to the wastewater system assessment, it can be used. However, data used in wastewater assessments needs to be relevant to the operating conditions to be tested. For example, the Water Availability Guidelines provides annual average rainfall scaling data, but an operating condition adopted for sizing of recycled water storages is the containment and reuse of inflows within wet years which requires consideration of rainfall at a higher temporal resolution.

Water corporations need to consider the operating conditions for which they are testing in the climate change impact assessment to identify the relevant climate projection data source, its limitations and uncertainty for the cases to be tested.

Climate projections represent the simulated responses of the climate system to a scenario of future emissions or concentration of greenhouse gases and aerosols (IPCC, 2021). They are typically derived using climate models.

The IPCC has developed various suites of emissions scenarios that help to account for uncertainty in projecting future greenhouse gas emissions in climate models. For their *Fifth Assessment Report* (AR5) (IPCC, 2013), these scenarios were based on four main Representative Concentration Pathways (RCPs).

Data representing possible future climate conditions are developed by adjustment of historical reference period data using climate scaling factors for climate scenarios. The recommendations of the Water Availability Guidelines should be applied: using a reference period of 1985-present and a high climate change scenario (RCP8.5) for the assessment of climate change impacts on wastewater systems. The need for sensitivity case climate scenario assessments is at the discretion of the water corporation and may be based on the outcomes of the recommended climate scenario or other factors. Example sensitivity case climate scenarios could include the post-1997 reference period method as recommended in the Water Availability Guidelines or a case to consider what may happen should climate change follow a lower projection such as RCP4.5.

An example of the cases for which climate data could be required is provided in Table 11 below and indicates some of the data considerations for each of the case assessments.

Table 11: Example cases for assessing the impacts of climate change on network capacity

<table>
<tr><th>Time</th><th>Base Case</th><th>RCP8.5</th><th>Optional Sensitivity Case Climate Scenario</th></tr>
<tr><td>Current conditions</td><td>Calibrated model using reference period data</td><td>N/A</td><td>N/A</td></tr>
<tr><td>2040</td><td rowspan="3">Population projections
Flow estimates based on historical climate conditions
Flow estimates based on historical sewage inflows</td><td rowspan="3">Population projections
Flow estimates based on RCP 8.5 Projected climate conditions
Flow estimates based on predicted future inflows/usage</td><td rowspan="3">Population projections
Flow estimates based on RCP 4.5 or other sensitivity case projected climate conditions
Flow estimates based on predicted future inflows/usage</td></tr>
<tr><td>2060</td></tr>
<tr><td>2075</td></tr>
</table>

A water corporation may also elect to include the climate change impacts on sewer hydraulic performance associated with an RCP4.5 scenario in its base case, as there is no longer a basis in science for considering any future scenario in which there is no climate change

Depending on the operating conditions relevant to the wastewater assessment, practitioners will gather data for climate scaling factors from a variety of data sources. These data sources are described in A.4.

Notes on Base Case Selection:

There is a range of choices in operating conditions and parameters that a water corporation can build into a base case as the reference point for isolating the climate change impacts. These are water corporation specific decisions.

Factors which are not materially climate change affected or are only indirectly affected by climate change conditions which can be either built into a base case and/or tested through a sensitivity analysis include:

1. Changes in wastewater flows due to population growth (likely increase) or changes in commercial or trade waste inflows (increase/decrease).
2. Changes in water usage patterns and increased water conservation (impacted by drought or other drivers) reducing inflows to sewers in future.
3. Deterioration of the condition of assets over time due to natural ageing or potentially an acceleration in the deterioration of condition from climate change such as sewers may experience more cracks in the pipes and thus more inflow and infiltration.
4. Changes in ground and groundwater table conditions. Groundwater infiltration changes resulting from climate change can be estimated in a model based on data from historical flow monitoring and groundwater table data, as follows:
    a. Determine the change in groundwater table level between a historical wet and dry season.
    b. Determine the change in groundwater infiltration rate between the same historical wet and dry season.
    c. Determine the rate of groundwater infiltration increase or decrease per meter of groundwater table increase or decrease.
    d. For coastal communities, estimate the expected increase in groundwater level resulting from sea level rise. Groundwater infiltration may reduce in locations remote from the coast.
    e. Apply the previous two dot point steps to determine the estimated increase or decrease in groundwater infiltration, which should be incorporated in the model.

Table 28: in Appendix A.4 provides a summary of how the key wastewater system climate conditions may change and includes guidance to be used for climate change vulnerability, risk and impact assessments. Further details on potential sources of climate data are provided in Appendix A.4.

An example of a sewer network asset that may be impacted by climate change in the future is discussed in the case study below.

CASE STUDY

Melbourne Water North Yarra Main flood gates – Emergency relief structures (Melbourne Water)

What:	There is an emergency relief structure (ERS) on the North Yarra Main near its junction with the Brooklyn Trunk Sewer. The ERS provides an outlet if flows are in excess of Brooklyn Pumping Station capacity and preference to the sewage flows from Hobsons Bay Main, which serves lower-lying areas, is required.
Climate change impacts:	The ERS outlet may be submerged under a moderate sea level rise and will most likely require relocation, redesigned or an alternative relief mechanism in the future.

3.3.3 Wastewater Network Capacity Assessment

Forecast increases in extreme daily or sub-daily rainfall for Victoria due to climate change has the potential to be a significant risk to service obligations related to sewer network capacity. A list of potential impacts on the wastewater network is included in Appendix A.1. This section suggests an assessment approach for the sewerage network hydraulic capacity (including spills). Guidance on the methodology and tools to identify potential impacts to sewerage network DWF spills, WWF spills and hydraulic capacity are provided (for comparison with a defined base case). Information within this section is intended to complement applicable sewer network standards.

Table 12 gives an overview of the four major components of sewage flow: DWF, ground water infiltration, rainfall derived inflow and infiltration (RDII) and exfiltration, and the anticipated impacts climate change will have on them.

Table 12: Sewage flow components and potential impacts

Sewage Flow Component	Description	Potential Impact due to Climate Change
Dry weather flow (DWF)	This includes sewage flows discharged to sewer by residential, commercial and trade waste customers. Residential DWF is sensitive to population and water usage/saving habits. While commercial and trade waste flows may increase or decrease over time as a function of a range of factors including economic conditions.	Reducing water consumption (due to the update of more water efficient appliances and adoption of water conservation during periods of drought) consequentially reduces discharges to sewer. Climate hazard conditions such as drought may also drive relocation of residential, commercial and trade waste customers which may increase or decrease sewage flows. DWF projections should be built into a base case. This may be supplemented by a sensitivity analysis of factors affecting per capita use, discharge to sewer and potential variability in non-residential flows.
Groundwater infiltration	Groundwater infiltration considers water ingress in non-rainfall periods through sewer structural failures (cracks) or at sewer joints (poorly sealed or affected by tree root intrusion) due to the sewer being temporarily or permanently below groundwater table. Groundwater infiltration is governed by the groundwater table level and how much of the sewerage network is under water.	Groundwater table level increase may be of particular concern for coastal communities which will be impacted by sea-level rise. In other areas it will depend on geographic increase or decrease in rainfall patterns. Groundwater should be built into a base case. This may also be supplemented by a sensitivity analysis.
Rainfall Derived Inflow & Infiltration (RDII)	This considers water ingress into sewers associated with rainfall events including through leaky maintenance hole covers, low lying leaky parts of on-property sewers and illegal stormwater connections to sewer and elevated groundwater table directly associated with rainfall events.	RDII will be impacted by changes in the intensity, duration, and extent of rainfall events (wet years, dry years). RDII is the most significant climate hazard condition to be considered in affecting the potential for increased spills (WWF), sewer network transfer capacity and the extremes of inflows received at wastewater treatment plants (maximum, range).
Exfiltration	Exfiltration covers water egress from a sewer into the surrounding groundwater table through structural failures (cracks) or at joints (poorly sealed) due to the sewer	This is unlikely to be directly affected by climate change but may be impacted indirectly through increased potential for tree intrusion. Exfiltration should be built into a base case. This may also be supplemented by a sensitivity

Sewage Flow Component	Description	Potential Impact due to Climate Change
	being temporarily or permanently above the groundwater table.	analysis. It is typically of lower magnitude than the other components.

Sewerage network hydraulic modelling is critical for the assessment of climate change impacts on sewerage networks. The accurate representation of climate scenarios through modelling must begin with an adequately calibrated model and involves use of climate projections to inform model parameters. Rainfall intensity/ duration/ geographic extent is typically the most impactful climate change condition to sewer networks, but this could vary depending on particular characteristics of the sewer network and the contributing catchment.

The general approach for assessing climate change impacts on sewer network performance is shown in Figure 13: and is to be read from the top left. The first choice that water corporations need to make is whether to adopt a ‘design storm’ event approach (*Approach A*) or a ‘time series’ approach (*Approach B*) as the foundation of the assessment of climate change impacts.

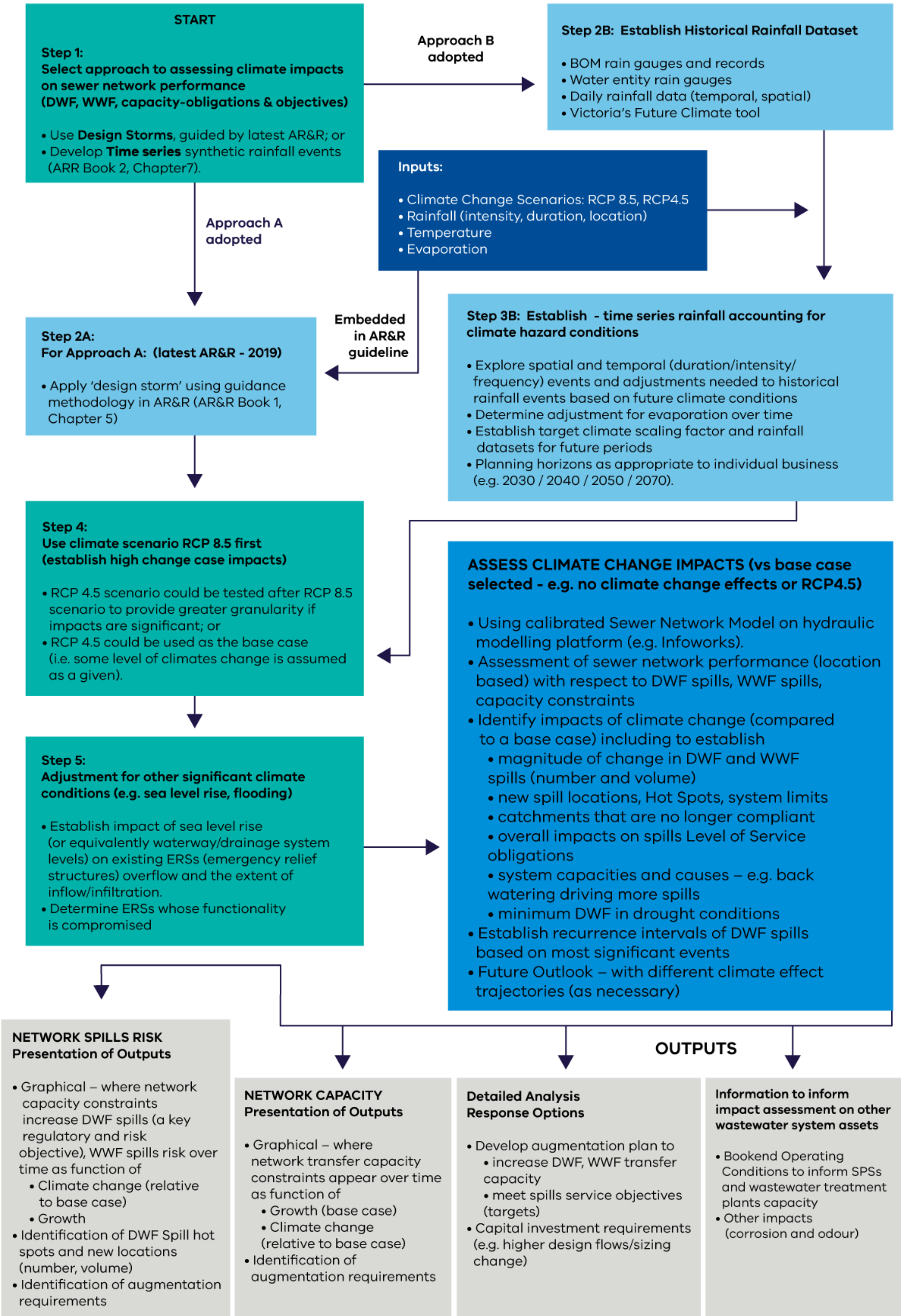


Figure 13: General framework for sewer network analysis of climate change effects on spills (DWF, WWF) and transfer capacity

Approach A is simpler and less resource intensive than Approach B in that the design storms (wet years, dry years – rainfall patterns, IFD) are stipulated in the 2019 AR&R guidance (Ball, J, *et al*, 2019), at Book 1, Chapter 5. These can be used as direct inputs into a calibrated sewer network model on a water corporation's hydraulic modelling platform (e.g., Infoworks, Mouse, other). However, this approach still has complexity including in interpreting the results from the many simulations (minimum of 120) required, time shifting of rainfall to coincide with peak DWF and subjective application of areal reduction factors. Some inputs may need to be adjusted depending on model used, e.g., future evaporation rates, initial catchment wetness to reflect a drier 25%ile, 50%ile and 75%ile starting condition.

Approach B involves developing a time series rainfall over a water corporation's nominated time horizon considering changes to the historical rainfall dataset to account for climate change conditions including rainfall (intensity, duration, spatial distribution), evaporation and other climate change conditions (e.g., sea level rise). The typical steps that would need to be undertaken, include:

- marshalling historical data rainfall data from available sources (e.g., BoM and water corporation rain gauges, Victorian Future Climate Tool) in temporal and spatial form. (Step 2B).
- using this as a base, adjusting it to establish a time series rainfall dataset[s] – spatial and temporal (duration/intensity/frequency) – under future climate change scenarios (e.g., RCP8.5) and the climate change conditions notably including evaporation and sea level rise. (Step 3B).
- establishing inputs to be used in a calibrated sewer network model on a water corporation's hydraulic modelling platform from Steps 3B,

The outputs from either Approach A (design storm event) or Approach B (time series approach) are the basis for the inputs to the water corporation's calibrated sewer network model. These inputs are then developed through Steps 4 and 5 of Figure 13:

- Step 4 (apply relevant scaling factors for the climate change scenario/s to be tested and identify the most significant wet weather events and the operating conditions required for assessments (refer Section 3.3.1)) and
- Step 5 (adjustments for sea level, waterway or groundwater table level rise attributable to climate change and causing increased submergence of emergency relief structures (ERSs) and/or sewer backwatering).
- *Note: Evaporation and sea/waterway/groundwater level rise are considered to be the most significant modifying factors to sewer network modelling to assess climate change impacts relative to a base case. These factors are used to either adjust the rainfall dataset or other model input parameters.*

Running the calibrated sewer model with these inputs will allow assessment of climate change impacts on the future performance of the water corporation's sewer network *relative to its selected base case* to predict:

- magnitude of change in DWF and WWF spills (number and volume)
- new spill locations, hot spots (where available hydraulic capacity is stretched and highest potential risk of increased spills), system limits
- catchments that are no longer compliant with regulatory spills objectives
- overall impacts on spills Level of Service obligations
- system capacities and causes – e.g., back watering resulting in more spills

The sewer model runs will also provide key outputs that are required for further assessments such as minimum flows (for odour and corrosion assessments).

While the time series approach is more resource intensive it has potential merit for better assessing the climate change impacts on the performance of large geographically widespread sewer networks. This is especially so where more detail is required in establishing performance outcomes (e.g., on the likelihood of DWF spills occurring) and where significant forecasted investment to address such climate change impacts is indicated and needs to be challenged and justified further.

The boxes to the right of the diagram are typical expected outputs from the sewer network modelling assessment which are necessary to either:

- demonstrate graphically and visually the climate change impacts over time
- establish the basis for planning responses to address unacceptable risk (refer Section 3.4) as a result of climate change impacts on service obligations and objectives and/or
- feed into further assessments (e.g., developing infrastructure and non-infrastructure responses and expenditure plans; inputs to WWTP assessments by providing relevant minimum dry weather and wet weather hydrographs accounting for future climate change conditions; hydraulic inputs into corrosion and odour wastewater network modelling assessments).

Other considerations which are at a water corporation's discretion include:

1. Modelling
    a. Each hydraulic modelling platform has its own parameters that can be modified and vary in some climate-sensitive processes. Factors for runoff from impervious/pervious areas, infiltration (e.g., soil types, leaky maintenance holes) are built into base model. These may also include how groundwater infiltration is modelled, evaporation accounted for or rainfall event intensity, duration and location.
    b. Sensitivity testing of modelling parameters including catchment imperviousness, precipitation intensity/duration/geographic extent, inflow/infiltration factors, roughness and blockage factors and household sewer loadings could be performed for sewer network analysis of climate change events. The extent of sensitivity testing needs to be commensurate with available resources and the benefits in obtaining better predictions and/or managing uncertainty. Consideration could be given to limiting this to representative storm(s) or the worst storm or some other event(s) defined by the water corporation.
    c. There are some specific wastewater system performance analysis and reporting required which differs between organisation (e.g., Sewer model build and calibration specification v8).
    d. The choice of grid sizes and time steps should be aligned with the water corporation's resources, needs and data availability. It is also relevant for the practitioner to consider how this aligns with the uncertainty of available climate change data.
    e. The value of performing numerous simulation iterations to achieve a higher degree of confidence in outcomes should be balanced against the value that it provides in the decision-making process and supporting communication of the climate change impacts. Each water corporation will need to decide the appropriate number of simulation scenarios consistent with business needs, resources and risk framework.
    f. Advancements in data analytics, machine learning and computing technologies can enable assessment of multiple data streams and scenarios over large catchments that were previously impractical to analyse and to account for multiple variable influences on the catchment response. An example includes the 'data cube' approach for analysis of multiple data sources including temporal, spatial, frequency and other grids. This approach can enable assessment of observed and predicted information from multiple sources to assess sensitivity of operating conditions and input variables to sewer network models and analytical tools for assessing network capacity response to climatic variability.
2. For efficiency reasons, by starting with assessing wastewater network hydraulic performance for the RCP8.5 scenario the more conservative case (high climate change) would be considered. A choice could then be made whether to expend further effort and establish the benefits to be gained (e.g., if more detail over time, where impacts are significant, is required by repeating the analysis for lesser climate change condition scenarios (i.e., RCP4.5).
3. VCP19 application-ready datasets do not include datasets on a sub-daily time-step and are therefore not available to directly utilise for sub-daily rainfall climate change projections (for Approach B).
4. Although AR&R 2019 is indicated, some water corporations may choose for resourcing or other reasons to explore the changed outcomes if the design storm(s) as indicated in AR&R 1987 was

adopted compared with the designs storm(s) as per AR&R 2019. This is only one way and not necessarily the best way to test the bounds of potential impacts and to establish a worst case depending on the water corporation's spatial and temporal features. A water corporation could explore other means of establishing and assessing a worst case noting that studies to date appear to indicate that the worst case ARR 2019 result tends to be larger or similar to ARR 1987, but the ARR 2019 median is significantly lower.

5. Some water corporations may choose as part of managing resources and focussing effort to target assets that are defined as critical (i.e., consistent with its corporate risk framework, those assets that have unacceptable consequences including on service obligations if failure was to occur). This should only be a short-term initiative. For modelling analysis, design storm(s) would be selected to test hydraulic performance of such critical assets.

6. General considerations include

   - a process to engage with the EPA on the application and interpretation of the modelling outcomes demonstrating climate change impacts. In particular, in establishing the storm events that are to be used for assessing network spills compliance (with front loaded, mid loaded or back-loaded storm events, all having the same IFD).
   - a need to align flows at interface points (e.g., in the Melbourne metropolitan area) if different approaches are adopted by the upstream and downstream water corporations.

The case study below provides an overview of Melbourne Water approach to assessing the impact of climate change on the sewer network through a continuous simulation framework and data cube project. More detailed guidance for application of the time series approach (Approach B) with reference to this Melbourne Water case study is also provided in Appendix A.9.

CASE STUDY

Melbourne Water Continuous simulation framework and climate data cube project

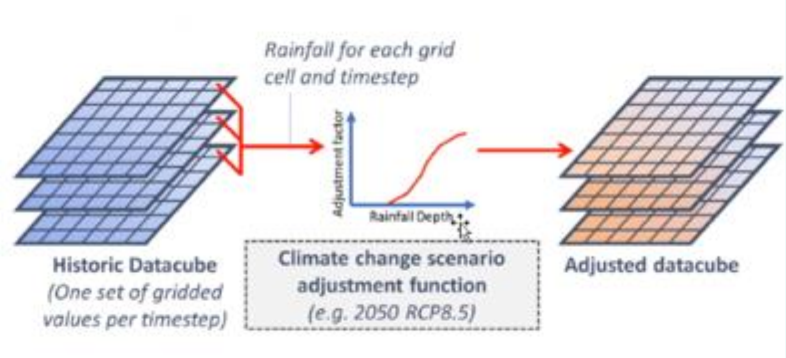
AR&R2019 discusses the application of continuous simulation – a computer model of a physical system that tracks the system's response/s to set rules – to flood estimation. Melbourne Water is pursuing testing of a continuous simulation approach to identify the wet weather flow capacity of Melbourne's sewer network. The current approach considers a range of "design rainfall events", corresponding to 1 in 5-year ARI or 18.13% AEP.

The design event approach requires consideration of variability in other inputs, including:

- Catchment area, which influences the areal reduction factor (ARF) and hence the design rainfall intensities for the catchment
- Defining a "critical" rainfall duration, which varies with the catchment area
- Temporal and spatial patterns of rainfall within the events
- Initial soil moisture
- Dry weather inflows.

This modelling task is complicated by the fact that sewer capacity estimates are required for every individual component of pipe infrastructure across the Melbourne Water sewer transfer network, and it is conceptually difficult to select a manageable number of design rainfall events that capture the complex interactions involved.

Continuous simulation is likely to offer a good solution for modelling wet weather flows in the Melbourne Water sewer system because it reconstructs the history of overflows with the current sewer network infrastructure. If the system is modelled for a sufficiently lengthy time period (e.g., 50 years), this should provide a relatively robust estimate of the 18.13% AEP design wet weather flow at each location in the system. Continuous simulation would avoid many of these issues because it is representing the response of the system at a large range of temporal and spatial scales. An appropriate spatial resolution that is consistent with the sewerage catchments, and a temporal resolution that is consistent with the rain gauges and response of the sewer system during wet weather events will need to be selected. A "data cube" of rainfall records has now been generated and testing of the continuous rainfall datasets is continuing.



It should be noted that this is a Melbourne Water specific example with an emphasis on how dataset(s) are developed and is not a data source for general use. It is also acknowledged that there are limitations in the accuracy of the source data from which these future rainfall sets are developed as there are fewer active pluviographs in the 1950-70s across Melbourne than the 2000-2010 period. This will improve over time.

3.3.4 Wastewater Network – DWF Spills performance (non-RDII)

Infrastructure and assets are more prone to failure as they age and are exposed to climate impacts outside of the original design conditions either in frequency or severity. Structural failure or service failure (e.g., due to tree root blockages) of wastewater network assets will likely lead to increased number and volume of DWF and WWF spills potentially breaching service obligations and objectives.

Future climate change conditions have the potential to increase the number, volume or frequency of spills. This could occur through:

- increased corrosion and earlier structural failure of corrodible assets, and/or
- increased structural or joint failure due to fluctuating soil moisture content, more extreme extent of drying and wetting cycles affecting ground movement; and/or
- increased tree root intrusion in lower rainfall, drought periods increasing the risk of structural and joint failure.

These climate change impacts are additional to those assessed from future RDII impacts (refer Section 3.3.3).

Leading practice to assess spills risks from these additional factors associated with climate change impacts is the use of predictive analytical tools. Predictive analytical tools, such as machine learning models and other bespoke models, can be used to establish correlations between climate conditions, assess the likelihood and consequence of failures in sewer networks and assist in prioritising the maintenance of high-risk assets. Importantly, after these tools/models establish correlations between DWF spills risk and climate hazard conditions, climate projections could be applied to identify the increased DWF spills risk due to climate change. For example, if soil moisture content variability impacts sewage spills performance, then the future variability in soil moisture content due to climate change both in the short and longer term (from relevant datasets) can be used as inputs to the model to establish future spills performance. This would allow targeting of investment to manage this to within objectives.

While all water corporations may not have the resources to adopt such tools there is the opportunity to learn from water industry peak body WSAA (Water Services Association of Australia) and leading practice forums and relevant increasing number of published case studies using such advanced tools.

Machine learning is increasingly being used to establish models to predict future performance. It uses data and algorithms to mimic the human learning process by improving accuracy over time *(https://www.ibm.com/au-en/cloud/learn/machine-learning)*. Appendix A.5 gives additional information about the general context, data and models and their importance and limitations. A wide range of statistical techniques is also outlined in Appendix A.5.

Machine learning is becoming an increasingly powerful tool, but it is not always the most appropriate or better than standard techniques. Whether or not machine learning is the most appropriate tool depends on the context, including the availability of sufficient data for causal parameters, in appropriate form, to allow both calibration and validation of the model. It can be effective where limited datasets of historical information are available, as long as there is sufficient data in appropriate form.

Machine learning is recommended to be used where:

- direct empirical formulae comprehending all the potential causal parameters affecting performance against an objective(s) are not available or
- statistical approaches are not best suited.

The ability to react to or prevent failures, based on actual network state, can benefit infrastructure and asset resilience to climate change. Machine learning may be used to consider the wastewater system response to a more immediate climate outlook (e.g., the following year's climate outlook) to prioritise asset maintenance within an existing program of works or forecast operational expenditure. While this concept doesn't make use of the climate science and projections covered by the Guidelines, an example general model construct is described in Figure 14 below.

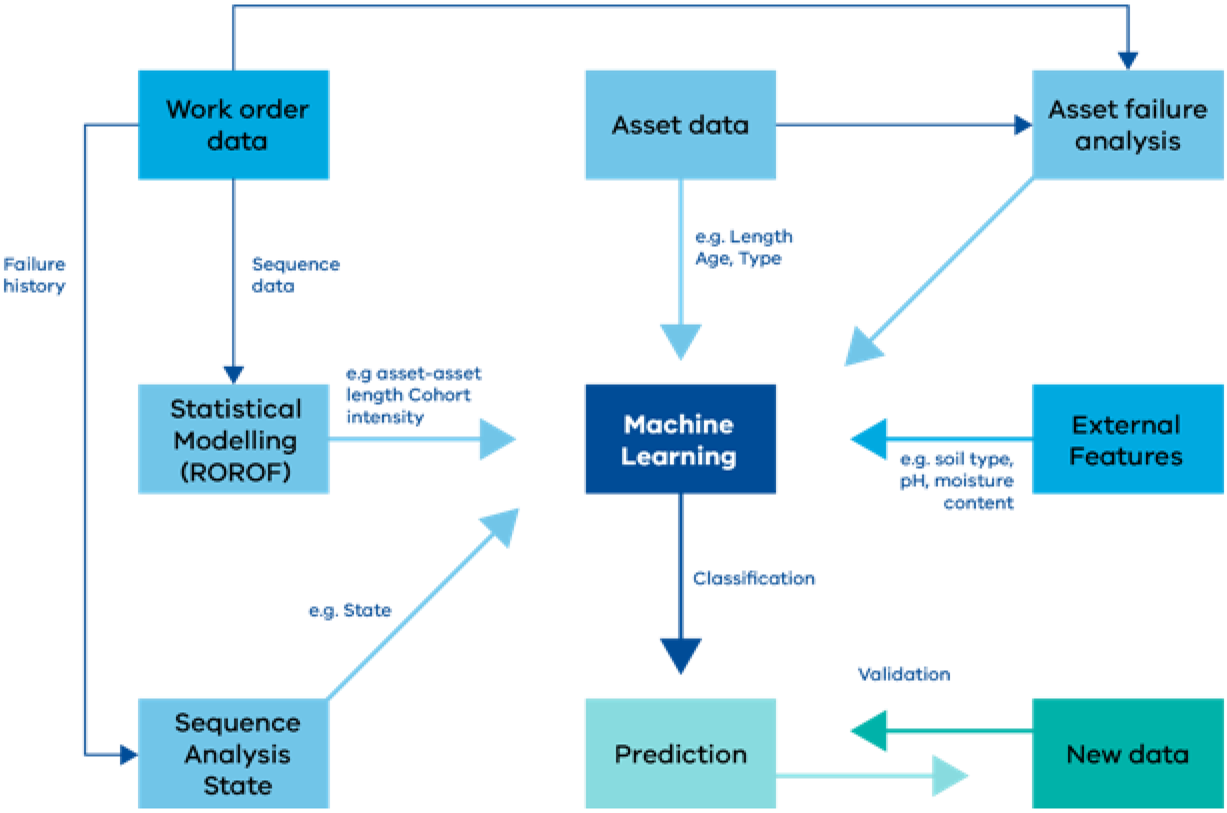


Figure 14: Sewer failure prediction (conceptual model)

Key issues to be addressed in developing an effective and successful model include:

- Having a sufficient, accurate and reliable dataset to both:
  - Develop a trained model (part of overall historical dataset), and
  - Validate the trained model (using balance of historical dataset).
- In developing and validating the model, ensuring that there are acceptably high true positives (correct predictions) and true negatives (correct predictions) and acceptably low false positives (incorrect predictions) and false negatives (incorrect prediction).
- Performance of the model A confusion matrix is simply a convenient means of tabulating the cooccurrence of model prediction and observations.
- Using and test the model to predict future performance (with new dataset).

The Sydney Water case study below provides an example where machine learning has established correlations between climate data and sewer performance.

CASE STUDY *Sydney Water Machine learning for asset maintenance*	
What:	Pilot predictive model for sewer chokes, through the following process: 2. Factor analysis – identify relative importance of each feature to contribute to accurate predictions. 3. Model development and training – identify and 'learn' patters in the data 4. Validation – test model against actual chokes 5. Prediction – predict location and likelihood of future chokes

	Aim to: • Reduce impacts of sewer chokes • Assist decision making for resource allocation • Improve compliance • Reduce disruptions caused by overflows, and • Reduce property damage costs
Climate change considerations:	The following are the most important considerations independent of whether AI or traditional statistical models are used. • Factor analysis included the following features, amongst other physical features: – Climate and soil data (rainfall, temperature, evaporation, soil moisture, soil type) – Tree data (tree coverage), and intersection with sewer assets within say 3 x canopy cover Factors found to have the highest influence on chokes caused by tree roots included "canopy coverage, length, depth, soil moisture, soil type, material, and laid year". These factors were also found to be interrelated and shouldn't be considered exclusively of each other when developing a model. Strong correlation was found between tree canopy coverage and other factors including pipe depth, pipe size, different tree species, tree growth/age and 6-month lag to climate factors (maximum temperatures, evaporation, and soil moisture)
Challenges and opportunities:	• Large volume of accurate and reliable data required • To be useful for informing future preventative maintenance, additional considerations are required – benefits include cost minimisation, reducing disruption times for customer, timing, and methods and reliability of inspections and cleaning. • Improve model by including other data such as tree species, soil temperature and particularly datasets for soil moisture variability accounting for climate change both in term and longer term. Highlighted a need for improved or new data, including accurate digitised asset data.

3.3.5 Wastewater treatment systems, recycled water and biosolids

This section sets out the methodology and tools to identify the impacts of climate change to WWTPs, recycled water treatment and reuse, and biosolids treatment and reuse. The impacts of the climate hazards will vary for each WWTP depending on the treatment processes adopted, and effluent reuse/discharge requirements. . Refer to Appendix A.1 for a list of example impacts to the wastewater treatment plant, recycled water and biosolids management systems from climate hazard conditions. This section aims to generally cover a wide range of wastewater treatment processes with a general suggested methodology and example typical inputs and assessment findings.

The methodology out-lined below assesses impacts from climate hazards against a base case. Further information about base case assumptions and selecting and developing climate change conditions is provided in Section 3.3.2. It is critical when assessing future climate impacts that the base case inputs (which are then adjusted for the identified climate change hazards) include future planning requirements such as:

- flow and loads projections,
- predicted changes to effluent quality targets,
- predicted changes to site limitations (e.g., odour emission limits)
- other key targets such as net energy neutrality, net-zero GHG, resource recovery and the opportunity for STPs to be part of a circular economy.

Whilst it is not a focus of the Guidelines, it is recommended that water corporations also consider the impact of WWTP operations on climate change. WWTPs consume significant energy and produce significant direct and indirect GHG emissions. In particular, the wastewater treatment energy and chemical demands and GHG emissions influenced by WWTP operational regimes. Through advances in current technology there is an opportunity to reduce energy usage and direct GHG emissions, reducing the contribution of the WWTP plant to climate change. Refer to Appendix A.8 for further guidance about reducing GHG emissions and energy use.

An overview of a suggested methodology to assess the impacts of climate change on key aspects of wastewater treatment, recycled water reuse and biosolids treatment and reuse is provided in Figure 15. This illustrates the key steps to take to assess the potential impacts, which are further described in Table 13 below. Appendix A.10 provides a case study of the application of the Guidelines.

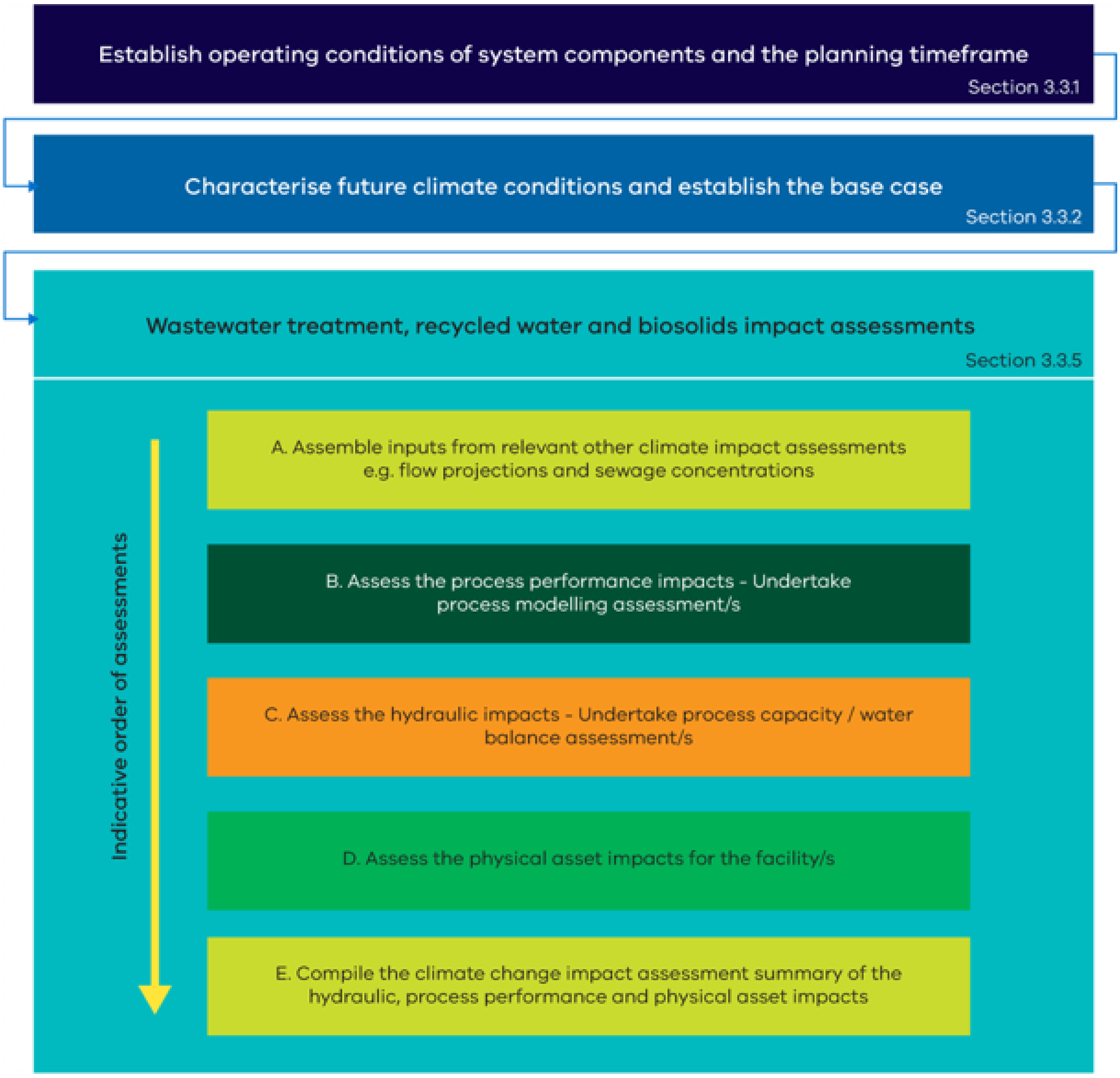


Figure 15: Steps for assessing climate impacts on wastewater treatment systems

Table 13: Description of steps for assessing climate impacts on wastewater treatment, recycled water and biosolids

No	Step	Approach
1	**Establish operating conditions and planning timeframe**	Operating conditions and the planning timeframe are selected, based on the wastewater treatment plant system assets, to provide average and 'bookend' conditions used in the design and assessment of the relevant assets, and a planning timeframe consistent with the study requirements. Preferably, these will have been determined previously (refer Section 3.3.1) to ensure the required inputs (outputs of previous assessments) are available for assessment of the wastewater treatment plant system. The following operating conditions would typically be relevant: Peak wet weather flow conditions to determine peak WWTP inflows to establish impacts on treatment plant performance and responses/requirements 'Wet' year to understand the impact of wet year conditions on key WWTP infrastructure impacted by climatic conditions such as reduced recycled water demands/ increased winter storage requirements and increased sludge drying pans area requirements 'Average' year to understand average conditions, and Minimum, 'Drought' year to understand the impact of drought year conditions on influent quality (reduced flows due to less groundwater infiltration and baseflow resulting in increased influent concentrations) and key infrastructure impacted by climatic conditions such as increased recycled water demands/ reduced winter storage requirements and reduced sludge drying pans area requirements. Note: Selection of the rainfall and evaporation percentile conditions, e.g., 90^{th}%ile or 95th%ile for a 'Wet' year, and 10^{th}%ile or 5^{th}%ile, for assessing the performance of relevant assets under climate change can be at the discretion of the water corporation, consistent with their regulatory requirements, design standards or contractual requirements (e.g., for supply of recycled water). However, these need to be consistently applied across the various assessments.
2	**Characterise future climate conditions and the base case**	It is suggested that wastewater impacts are first assessed for the RCP8.5 scenario i.e., the more conservative case (high climate change). A choice could then be made whether to expend further effort and establish the benefits to be gained (e.g., if more detail over time where impacts are significant) is required by repeating the analysis for lesser climate change condition scenarios (i.e., RCP4.5). Alternatively, a water corporation may elect to include the climate change impacts on wastewater treatment plant system performance associated with an RCP4.5 scenario in its base case, as there is no longer a basis in science for considering any future scenario in which there is no climate change.
3	**Wastewater treatment, recycled water and biosolids impact assessments**	
A	Assemble inputs from relevant other climate impact assessments e.g., flow projections and sewage concentrations	Refer to Figure 12. The wastewater quality and loads are determined based on the predicted future inflow rates and design population, drawing on influent sampling data where available. For the minimum flow, drought conditions, experience from the Millennium Drought could be considered to inform the influent quality predictions. Previous assessments of climate-related impacts on wastewater characteristics have shown that constituent loads (chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), TP, suspended solids, H_2S and TDS) increase independently of uptake of flow reduction (e.g., water efficiency initiatives) as loads are typically based on residential population, commercial and industrial trade wastes and the mass of solids entering the sewage network (Jacobs, 2011). WWTP influent flows are determined for the base case and each climate scenario, and for the operating conditions. Where available, the plant influent flows should be adopted from the network and flood modelling and climate impact assessments undertaken as per Section 3.3.3 (for the same climate change scenario and operating conditions).

No	Step	Approach
		If detailed network and flood assessments based on the climate change scenario conditions are not undertaken or available, assumed sewage flows can be adopted to inform a preliminary assessment of climate change impacts, for example, by adopting a % increase in inflow (relevant to the operating conditions being assessed) based on the assessment results for a similar catchment. If the wastewater system includes the use of recycled water, recycled water demands are required to be estimated for the climate change scenarios and operating conditions (refer Section 3.3.1 for further guidance) to inform the climate impact assessment for these assets. If the wastewater treatment plant discharges to the environment, limitations on effluent discharge are required to be determined. With the impacts of climate change, there may be additional limitations, for example: on effluent discharges to creeks and rivers during periods of low flows or reduced hydraulic capacity in effluent discharge pipelines due to flooding or sea level rise (refer Section 3.3.6).
B	Assess the process impacts - Undertake process modelling assessment/s	Process modelling / process capacity and water balance assessments are undertaken for the wastewater treatment assets to assess the potential impacts of climate change. To assess the impacts of potential climate-related changes, process modelling tools such as BioWin™ and Sumo® (process aspects), bespoke hydraulic models and/or excel based tools can be used. For many assets, the tools used to design the asset, or assess the asset capacity will be relevant for the assessment, and water corporations can continue to use these, with the relevant changes to the design inputs to account for the climate change scenarios. Climate change scenarios and operating conditions inputs will provide a range of settings that can be modelled to determine the effects on wastewater treatment plants from climate change conditions. Examples include: • peak wet weather events, • reduced flow events related to drought and water restrictions, and • warmer sewage/ambient air temperatures. To predict the impact of climate change on the wastewater treatment assets update the design tools and models with the baseline conditions (e.g., population growth) and then rerun/remodel with the relevant climate change predictions and compare the model outputs. Refer to Appendix A.1 for examples of potential impacts on wastewater treatment plant systems due to climate change.
C	Assess the hydraulic impacts - Undertake process capacity / water balance assessment/s	As per above item
D	Assess the physical asset impacts for the facility/s	• Odour and corrosion At the sewer inlet to the WWTP the key risk period will be during low flow periods, where higher influent concentrations and increased retention times in the sewer are likely to be observed, potentially resulting in higher concentrations of odorous compounds and H_2S being received at the WWTP inlet. These inlet concentrations will be determined from an assessment of sulphide and odour generation in the upstream system as impacted by climate change and which will be particularly affected by the extent of daisy chain pressure / rising mains in the upstream network and the network residence times. In the wider treatment plant, the impact of climate change can be assessed with the running of odour models based on baseline and climate change conditions. For the climate change conditions the models can be updated with modified area requirements for the key process units and odour generation rates informed by standard WWTP process models or empirical equations that account for climate change conditions (e.g., temperature, relative humidity of fresh air drawn in as

No	Step	Approach
		part of force ventilation of components of the wastewater system), and any predicted increase in sulphides. Refer Section 3.3.7. • Flooding and coastal conditions The site risks for flooding and sea level rise risk are assessed and infrastructure at risk of inundation/damage is identified. For wastewater systems that discharge treated effluent to coastal discharges, a hydraulic assessments of flow capacity under climate change sea level rise and storm surge conditions or waterway levels at the discharge locations is required to determine the potential impact on effluent discharge capacity. Refer section 3.3.6. • Asset integrity and design life Asset integrity and design life risk assessment assesses the potential impact of climate change on the treatment plant assets. Refer section 3.3.6 • Bushfire risk Infrastructure at risk (and at increased risk due to climate change) of bushfire damage is identified. This includes assessing key site supply infrastructure including roads, power supply and communications for plant monitoring. Effluent quality may also be adversely impacted temporarily. Refer section 3.3.9
E	Compile the climate change impact assessment summary of the hydraulic, process and physical asset impacts	The key potential impacts of climate change on the wastewater treatment plant assets are compiled to have a complete understanding of all risks for that plant's assets. Whilst there are many different process configurations, influent characteristics, treated effluent discharges and site conditions, the assessment is likely to identify key areas of focus for the wastewater treatment system. Example impacts that may be observed for a range of wastewater treatment assets are summarised in Appendix A.1. To provide a single point of reference, this table includes risks from odour and corrosion, bushfires, flooding and asset degradation as identified in relevant sub-sections of this Section.

3.3.6 Flooding and coastal risks

This section sets out the methodology and tools to identify risk of flooding of infrastructure and equipment as a result of rainfall and sea level rise due to climate change. Appendix A.1 provides example impacts from flooding and sea level rise risks that may be observed for a range of sewer network and wastewater treatment assets.

With climate change predicting increased frequency and intensity of rainfall events, and sea level rise, new and existing assets may be susceptible to significant damage due to more frequent and/or higher floods and sea levels.

Protecting assets will depend on the vulnerability and consequence of failure of each, on a case-by-case basis. If the asset is designed to withstand flooding, the consequences of flooding to the asset are low, or the asset is located in an area where there are no sources of flooding, there would be no need for a climate impact assessment. The assessment of flood risk will be dependent on a number of factors:

1. The nature of the assets
2. The consequence of damage, loss of service or damage to the asset
3. The location of the asset
4. The available data
5. The service life of the assets.

The above factors assist a vulnerability screening assessment. For areas with available data, there will be a continuum of historic information such as the flood record through to available flood models.

Flood modelling is a tool that can be used to identify areas at risk of flooding. Many areas of Victoria have been modelled to determine their risk for flooding by catchment managers and local councils. Authorities are encouraged to share information from flood studies with other authorities so that decision making is informed by the best available data (Guidelines for Development in Flood Affected Areas, DELWP 2019). Flood models should be developed in accordance with the relevant authorities' guidelines and advice outlined in AR&R 2019 (Ball et al, 2019).

Where flood mapping from a flood model is available for the full range of flood events in terms of AEP, the procedure outlined below should be followed.

For situations that do not have the full data requirements it will be necessary to infill this data. It is important that the effort to infill the data is proportionate to potential consequences.

When identifying assets in flood areas consider:

- sewerage network assets (such as pump stations, manholes, and surcharge structures).
- sewage treatment assets. Sewage treatment assets at risk include threats to mechanical and electrical equipment, roads (and access to the wastewater treatment plant), lagoons, levee banks, and retaining basins.
- access and egress

If the screening assessment demonstrates that there is a significant consequence from flooding of the asset it would be necessary to undertake a flood climate impact assessment. The available data and potential consequence would dictate the details of the assessment. For situations where there is no data, a flood model would need to be developed that is proportional to the likely consequences.

The need for flood modelling using the latest climate data/projections can be determined via the process shown in Figure 16 below.

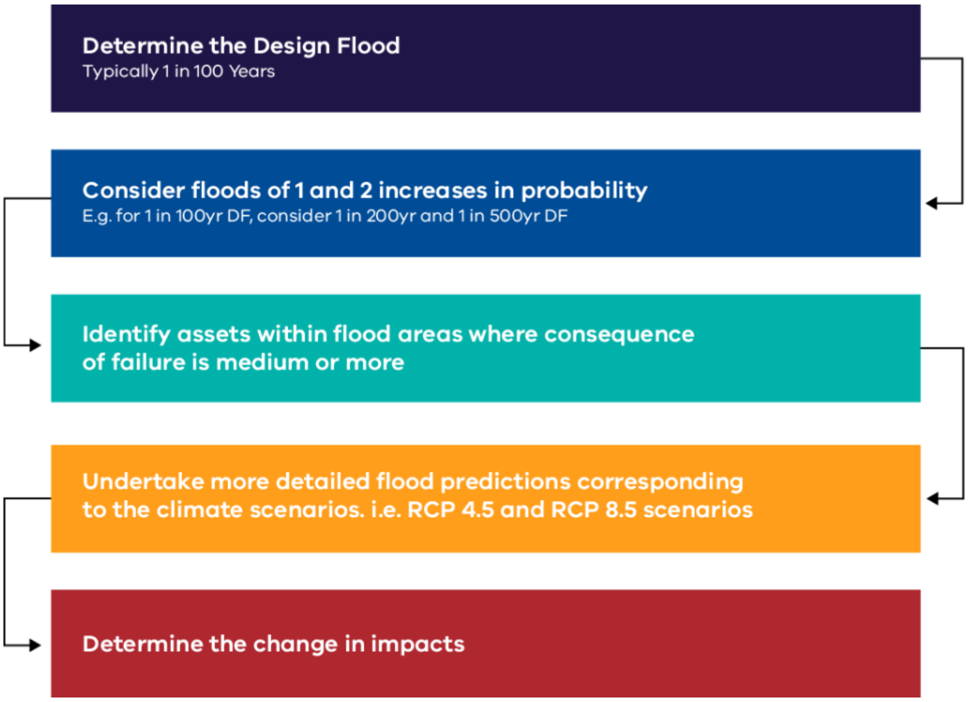


Figure 16: Process to identify need for flood modelling

The impacts of flooding on inflow infiltration into sewers and increased wet weather sewer flows ought to be undertaken in the assessment of sewer network hydraulics (climate change versus base case) as described in Section 3.3.3. It may be appropriate to model multiple design floods to align with the design storms assessed in network models to inform inflow and infiltration. In particular, with reference to the methodology outlined in Figure 13:, the impacts of flooding could be accounted for in Steps 4 and 5 in Approach A and/or more generally for both Approach A and B adjusting the standard inflow-infiltration factors built into the network hydraulic modelling tools (e.g. Infoworks) in the "Assess Climate Change Impacts" step.

A coastal hazard assessment may also be required to:

- Identify assets (such as pump stations, WWTPs, and surcharge structures) that may become inundated due to sea level rise and/or storm surge (also consider tides and impact on river levels – hydraulic limitations).
- Identify weak points in the system where the network may spill or back-up to surcharge and structurally stress maintenance holes.
- Identify sewer network areas that will become inundated, saline water inundation impacts on pipes and STP process (as covered under Section 3.2.2)
- Access and egress

Where the asset is potentially at risk from multiple sources of flooding such as rainfall induced and coastal flooding, assessments should consider the risk of a combination of events occurring simultaneously. This should not simply be the combination of equivalent probability events e.g., the 1% AEP flood event with the 1% AEP coastal event, as this will lead to an overestimate of flood levels. For high consequence situations a joint probability study would be recommended, whereas simple combination equivalent probability events are acceptable for low consequence situations.

From the above modelling and assessments, the location and predicted flooding and sea level rise can be assessed to determine the impacts of climate change. 3.3.73.3.7

3.3.7 Odour and Corrosion Risk

This section sets out the methodology and tools to identify potential changes to odour and corrosion risks as a result of climate change.

With climate change there is a potential for significant odour and corrosion (O&C) issues for wastewater networks and treatment plant assets. Odour emissions and corrosion rates compared to current baseline operation, are likely to increase, in particular within the sewer network, due to operation with higher risk conditions (for example higher sewage temperatures, reduced flowrates and changes to ventilation rates). In turn, odour can lead to poor reputation in the community and corrosion to unplanned asset failures.

Hydraulic and sulphide modelling can be used to predict and quantify the impact of changes on dissolved sulphide and H_2S, based on predicted changes to input parameters. Models available include spreadsheet tools (developed based on empirical equations), and proprietary models such as: WATS / SeweX; and linked hydraulics / WATS-SeweX /ventilation models.

Odour dispersion modelling can be used to quantify ambient odour impacts to surrounding receptor sites under different H_2S and odour emission scenarios at designated locations typically vent stacks. Refer Appendix A.5.8 for discussion of odour and corrosion models.

Key hydraulic and sulphide prediction model inputs that may vary due to the impacts of climate change are the following:

- sewage flowrates (sewage residence times),
- sewage quality,
- sewage temperature,
- air flowrates (for gravity systems, natural ventilation or pumped), and
- humidity levels.

To predict the impact of climate change on odour emissions and corrosion rates in wastewater network systems and wastewater treatment plants:

1. For wastewater network systems:
   a. Run wastewater network model scenarios for baseline and climate change scenario operating conditions. Typically, the model run scenarios will apply elevated wastewater temperature and variation in wastewater flows and residence times to predict corrosion rates and gaseous H_2S concentrations.

b. Run ventilation modelling for natural ventilation or forced ventilation (as appropriate) for the sewer. Climate change scenarios will typically have increased temperature and both increased and decreased relative humidity of vent induct air to be tested. Relative humidity (RH) is a key parameter affecting corrosion rates (of corrodible assets) and testing of a range of potential RH conditions under climate change should be undertaken

2. For wastewater treatment plants Run odour dispersion models for baseline and climate change scenario operating conditions.

   a. If available, the risk of increased odour and corrosion at the plant inlet can be informed by the network corrosion and odour risk assessment outputs, with the network assessment providing an indication of the future potential risk of higher odorous compounds (and H_2S) being received at the WWTP inlet.

   b. For the wider treatment plant, odour dispersion modelling can be run for baseline and climate change conditions. For climate change conditions, the adjusted inputs will depend on the network outputs (e.g., H_2S concentrations), process units and climatic conditions, and care will be required by the designer to adopt appropriate inputs. The impact of climate change on odour emission rates has not been widely researched, and advice from odour specialists will be required.

From the above modelling and assessments, the location and predicted odour emissions and rates of corrosion can be assessed to determine the impacts of climate change. Example impacts from O&C risks that may be observed for a range of sewer network and wastewater treatment assets are summarised in Table 14.

Table 14: Potential impact of climate change parameters on odour and corrosion risks at wastewater network and STP

Asset Type	Potential O&C impact at network and WWT assets
Sewer Network and Sewer PS	• Increase in average sewage temperatures, resulting in increased sulphide generation rate in network, increased release of H_2S to sewer gas space. Increase to network O&C risk. • Higher sewer gas space temperatures resulting in increased corrosion rates in network. Corrosion rate is proportional to gas phase temperature. • Increase in sewer gas buoyancy due to increased temperature resulting in increased rate of foul air outgassing at network vents and wastewater network openings (e.g., leaking manholes). Increased network odour impact risk. Bernoulli effects (function of wind speed) and varying sewage levels are also factors to be considered. • Ambient air relative humidity may vary as a result of climate change, with greater variation between seasons, speeding up corrosion of corrodible assets. • Higher sewer gas space humidity (i.e., kg moisture per kg dry air) may occur due to increased sewer gas temperatures, resulting in increased corrosion rates. Corrosion rate is proportional to gas phase relative humidity, with corrosion rate increasing significantly for relative humidity increases above 85%. • Higher ambient relative humidity may cause a lower driving force for naturally ventilated sewer systems, less dilution of sewer gas space, resulting in higher H_2S/odour levels in sewers. Overall increase in O&C risks for networks with natural ventilation. • Higher ambient relative humidity may cause reduced efficacy for forced ventilation systems used for corrosion mitigation to control sewer gas space relative humidity. • More intense rainfall events may cause greater turbulence at locations throughout the network, resulting in increase in H_2S release rate to sewer gas space. Increased O&C risk. • Increased rate of seawater ingress to network via infiltration for coastal catchments. Results in higher sulphide generation rates, specifically in pressure mains. Overall increase to O&C risk.
Wastewater Treatment Plant	• Increase in H_2S of wastewater discharged to WWTPs. Overall increase to O&C risk. Highest WWTP risk areas expected to be process units most susceptible to H2S gas release, i.e., at inlet works and PST.

Asset Type	Potential O&C impact at network and WWT assets
Sewage Network and Wastewater Treatment Plant	• Changes in wind speed, direction and atmospheric stability may impact atmospheric dispersion conditions and associated impacts of odour plumes (in the air and at ground level). Low risk of material impact. • Reduction in average flows may cause longer sewage residence times in network and subsequent higher sulphide generation rate. May also impact sewer gas composition (e.g., H_2S, mercaptans and other reduced sulphide components) due to changes in extent of anaerobic conditions.

CASE STUDY *Example 1 Eltham sewer (Yarra Valley Water)*	
What:	Yarra Valley Water's Eltham sewer consists of a 13.5 km long trunk main, located approximately 20 km north-east of Melbourne's CBD. Approximately 7.5 km of this sewer is unlined corrodible material with a diameter ranging from 750 to 1600 mm. There are 13 vents along the sewer for the purposes of natural ventilation. The sewer operation has contributed to several odour complaints and was prioritised by Yarra Valley Water for odour and corrosion investigation. The investigation included the identification and assessment of options to significantly reduce or eliminate odour and corrosion risks attributed to the sewer. This involved the sulphide and ventilation modelling of H2S(g) in the sewer gas space, as well as estimation of corrosion rates. The modelling represents a baseline assessment using current condition data for sewage flow rates and ambient conditions.

3.3.8 Asset Integrity and Design Life

This section sets out the methodology and tools to identify potential changes to asset integrity and design life as a result of climate change.

Climate change is likely to reduce the integrity and design life of wastewater assets, due to accelerated material fatigue and degradation from climate change impacts such as extreme storm flows, higher temperatures, fluctuation of soil moisture, floods and continued periods or low flows.

The likelihood of unplanned asset failures and a need to bring forward asset renewals and upgrades increases. This in turn is likely to affect the water corporation's reputation, perception within the community and ability to achieve service obligations.

Traditional condition assessment and physical tests of assets (i.e., pipe wall thickness tests) only consider the current condition of the asset and do not account for change in the potential integrity and design life of the asset due to climate change.

Proprietary models to predict asset degradation are available that consider asset life reduction due to climate change. These are typically black box and of limited assistance to water corporations in understanding climate change impacts on assets other than in a general sense.

To account for the impacts of climate change, water corporations could develop modified degradation curves using available literature incorporating temperature and other effects. As these effects are likely to be slow moving, the use of modified baseline degradation curves supported by condition assessment and monitoring programs would allow timely action to avoid failure and to adopt more resilient materials.

Asset degradation curves are used in asset management modelling to predict residual asset life. An asset degradation curve's purpose is to plot and analyse deterioration of an asset over time and illustrate how assets fail over time. These curves allow for early detection of failure and can assist in reducing asset risk and inform planning and scheduling of renewals.

Standard asset degradation curves should be adjusted to take account of the following climate change effects:

- Increased air and ground temperatures

- Soil moisture content
- Changes in groundwater salinity
- Changes in sewage concentration resulting corrosion (refer to Section 3.3.7 for further detail on assessment of corrosion impact)

WSAA Condition Assessment Guidelines for Mechanical and Electrical Assets Guidelines Report provides a visual representation of outlining how asset degradation curves can be used to identify:

- Functional failure – is the inability of an asset to meet specified performance standard or inability of asset to function at the level of performance that has been specified as satisfactory; and
- Potential failure – is an identifiable condition that indicates function failure is imminent

The ability to identify either a functional or a potential failure depends on three factors:

1. Clear definitions of the function – what are the functions and associated desired standards of performance in present operating context? i.e., function of pipe within a network and required performance to achieve service obligations and objectives
2. Identification of conditions that constitute functional failure and failure modes – in what ways can it fail to fulfil its functions? What causes each functional failure? i.e., unplanned failures caused by corrosive soils damaging a pipe joint
3. Identification of conditions that indicate imminent failure (failure effects) – what happens when each failure occurs? i.e., potential spills within the network, interruption to service

Processes to manage increased potential for accelerated degradation could including changing to algorithms used for estimating residual asset life (e.g., where temperature, rainfall and extent of increased corrosion are included).

Examples of functional failure modes that should be updated to account for climate impacts are shown in Table 15.

Table 15: Examples of functional failure modes should be updated to account for climate impacts

Asset Type	Potential impact due to climate change
Mild steel cement lined pipelines	• External corrosion due to increased soil corrosivity and damaged, delaminating or missing coatings • Internal corrosion (as described in Section 4.2.2.4) • Joint movement (degradation of joint material)
Cast iron cement lined pipelines	• External corrosion due to increased soil corrosivity and damaged, delaminating or missing coatings • Joint movement (degradation of joint material) • Tuberculation where internal lining has failed or missing (older unlined pipes)
Ductile iron cement lined pipelines	• External corrosion due to increased soil corrosivity and damaged, delaminating or missing coatings / sleeve • Joint movement (degradation of joint material)
Plastic (PVC, PE and Glass Reinforced Plastic)	• Ultra-violet (UV) radiation and heat intensity (above ground installations) • External loading damage e.g., point loading from rocks/stones in bedding material (below ground installation) – voids created in bedding material
AC pipelines	• Internal / eternal corrosion • Fracture pipework due to ground movement
Valves	• Corrosive environments

Asset Type	Potential impact due to climate change
	• Changes to sewage quality, siltation, etc.
Pipelines (general)	• Decreased soil moisture increased tree root intrusion • More frequent pipe full surcharging can lead to erosion of backfill surrounding pipes through degraded rubber joints (EW pipes) or cracks/holes (all pipes) and create voids that can lead to collapse.
Mechanical and electrical assets	• Corrosive environments • Ambient temperatures – increased days over the temperature rating of electrical equipment or increased temperature cycling effects • Ultra-violet (UV) radiation and heat intensity
Lagoons, retaining basins, levee banks	• Changing soil moisture conditions resulting in damage to clay core or surface • Flexible covers – reduced asset life due to higher UV – structural loading of covers associated with water loading / higher intensity rainfall events • Increased erosion when subject to higher flows resulting increase rainfall intensity (e.g., structures adjacent to drains / waterways • Foreshore flooding / foreshore erosion for to storms (e.g., structures located on bays and ocean shorelines
Concrete pipeline and structures	• External soil corrosion / corrosive environments (including increased corrosion rates due to higher ambient CO_2 concentrations) • Internal corrosion (as described in Section 4.2.2.4) • More frequent surcharging in manholes and structures due to higher intensity rainfall leading to increased internal pressure and structural failure (fatigue failure) • Inundation and undermining of structures and pipelines
Above ground assets	• Degradation and reduced asset life through exposure to increased ambient temperatures and UV radiation (e.g., plastic pipes)
Gravity network assets	• Increased frequency of inflow surcharges – additional pressure on assets (e.g., manholes) – further compromised by changing earth pressure (fluctuating soil moisture)

3.3.9 Bushfire risks

Bushfire may pose a significant risk to elements of the wastewater system in some settings, with the potential for significant damage to above ground assets in highly bushfire-prone locations. Bushfires may also disrupt the operation of the wastewater system due to (e.g.) damage to power supply networks and fire-affected trees blocking site access roads. Refer to Appendix A.1 for Examples of how climate change may exacerbate bushfire impacts on wastewater systems.

Bushfire hazard assessments are used to provide a basis for identifying areas and assets at risk from bushfires and to plan for risk mitigation. They are the magnitude of risk, protection measures for mitigation, and are a requirement for new infrastructure located within the Bushfire Management Overlay (BMO) areas (see *Planning Permit Applications, Bushfire Management Overlay Technical Guide* (DELWP, 2017)).

Planning for new wastewater infrastructure within the BMO would follow pathway two in the DELWP (2017) bushfire planning technical guidance. This involves four main steps:

- Bushfire hazard landscape assessment: which provides information on bushfire hazard exposure between 150m and over 20km from a development site. The assessment describes vegetation extent, topography, fire weather conditions, expected patterns of fire spread and access,
- Bushfire hazard site assessment: considers bushfire hazard (from vegetation and slope) in the immediate vicinity of the development site and informs defendable space calculations sand building construction requirements, following AS 3959:2018 Construction of buildings in bushfire prone areas.

- Bushfire management statement: which is prepared by or on behalf of the development permit applicant. It shows how a proposal has responded to the bushfire hazard site and landscape assessments and documents how approved risk mitigation measures (i.e., defendable space, access provision, fire water supplies) will be applied. It demonstrates to a local government authority that a planning permit should be granted.
- Bushfire management plan: which must show that all planning requirements have been met, including any conditions relation to managing the defendable space, water supply and vehicle access.

A bushfire hazard assessment (as per DELWP, 2017) should include information on the bushfire hazard on and near a site and set out appropriate bushfire protection measures such as defendable space, building construction requirements, water supply and access.

For long-lived wastewater system infrastructure, the bushfire hazard assessment as part of contextual information on the site, the hazard assessment should consider potential changes in fire weather conditions and fire behaviour as a result of climate change over the life of the asset . This can be done by modelling changes to the Fire Danger Rating (FDR) that stem from changes in fire weather (as discussed in Appendix A.2). The climate change informed bushfire hazard assessment may lead to increased defendable space provision, changes in infrastructure construction or reconsideration of site selection.

3.4 Including climate change impacts in risk assessment and prioritisation

PRACTITIONER'S GUIDE

This section will assist you to:

Assess the risks to objectives. Are there risks that require interventions to adapt to climate change?

This phase seeks to review the risks to objectives with the outcomes of the climate impact assessments and identify what matters most.

The preceding sections have considered the potential impacts of climate change on wastewater systems. But which impacts require intervention to deliver on a water corporation's commitments to customers, stakeholders and regulators?

Risk assessment and prioritisation of climate change related risks can support a resilient wastewater system for Victoria: one that is prepared for, able to withstand and then recover and learn from disruptive trends or events.

At this stage of assessment of the impacts of climate change, the practical consideration of what may happen if the wastewater system is not resilient should also be considered. Traditional asset management processes are based on just enough-just in time investment, concentrating on satisfying customer service levels and complying with regulatory requirements (e.g., EPA licence conditions).

Maintaining infrastructure to mitigate these risks is essential. However, the current approach to risk management results in decisions being made to "patch" the system to maintain the status quo. While it may be adequate when dealing with known or foreseeable changes and predictable systems, this approach can erode resilience when the external environment is changing rapidly.

Regulatory change, population growth, climate change and events need to be considered in the decisions to increase flexibility and provide a "safe operating space" for those delivering wastewater services. The wastewater system is complex and highly interconnected. Risk management needs to reflect this. It must consider how the system will respond and how service delivery is affected when upstream and/or downstream assets are operating abnormally, and external system limits are approached.

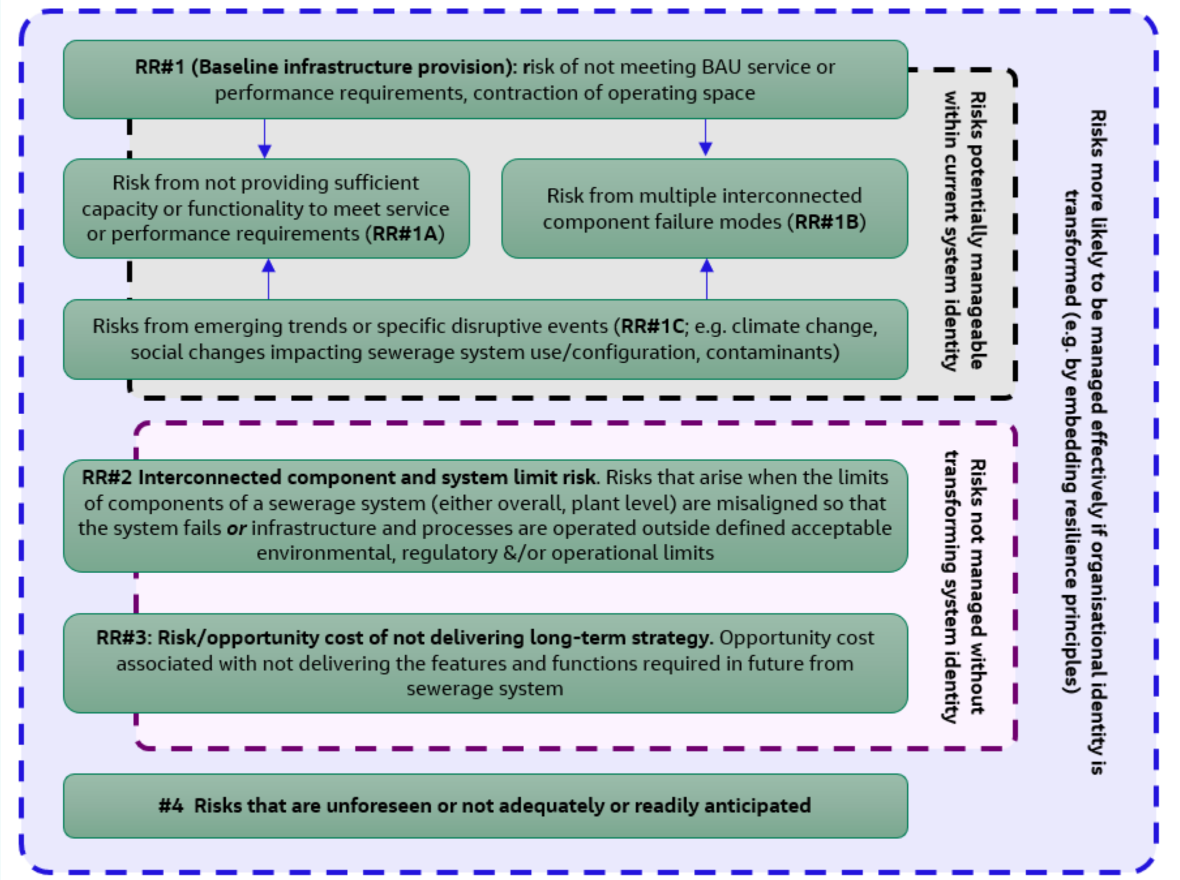
Risk management also needs to enable the pursuit of opportunities to deliver strategic objectives and realise the benefits that are anticipated to arise from this. There is a link between water resource management and treated water generated by wastewater systems, and both are impacted by climate change. In particular the wastewater system should be seen as part of the whole water cycle with a potential capability to increase resilience and contribute to water resource management objectives. This could be achieved through appropriate treatment of wastewater to produce water of a quality suitable for use by either substitution of current uses freeing up surface water sources or meeting new or alternative water uses or contributing to potable water supply shortfalls including as driven by climate change effects.

CASE STUDY

Resilience risk types to support the practical consideration of what may happen if the sewerage system is not resilient

The Case for Change project (Melbourne Sewerage Strategy: Developing the case for change, Melbourne Water, 2019) identified four types of resilience risk (RR) framed to respond to this complex risk management environment and expand the way water corporations think about and manage risks associated with the sewerage system.

- *RR #1: addresses circumstances where the wastewater system is unable to meet "service or performance expectations. This may result from:*
  - *Not providing sufficient capacity or functionality to satisfy service or performance expectations (RR#1A)*
  - *Failure of multiple interconnected components or a combination of events causing overall system failure (RR#1B) under foreseeable operating conditions.*
  - *Failure to anticipate changes in external environment which may occur over time and compromise existing capacity or require new capacity (RR#1C)*
- *RR#1B risks could be addressed by providing appropriate operational flexibility to manage through such failure events.*
- *RR#1C risks may arise because emerging trends or issues (including changed social habits or use of the sewerage system, climate change and emerging contaminants) have not been anticipated and/or addressed in a timely or effective manner, thus triggering type RR#1A or RR#1B risks.*



RR#1 reflects routine risk management by water corporations, where the focus is on continuing to provide infrastructure to meet regulatory obligations and customer service requirements. Risks arise from single or multiple interconnected component "failures" and as the system does not adapt in response to disruptive events or trends.

RR#2 and **#3** are not readily addressed by routine risk management or through incremental change or adaptation. Transforming towards a circular, resource recovery system may allow the system to operate safely within its limits and enable circular economy benefits to be realised.

Some risks (RR#4) are not readily anticipated or directly prepared for because of their severity, combination, or sequencing. The identity of resilient organisations is underpinned by principles like those defined for Melbourne Water (above). They are better equipped to respond to risks for which no direct preparations have been made.

Figure 17: Conceptualization of resilience risk types

- *RR#1 comprises the types of risk that water corporations have traditionally focussed on and is most comfortable dealing with. The main focus has been on RR#1A risks; there is an increasing need to consider RR#1B and RR#1C risks and risk responses.*
- *RR #2: considers the interactions and interconnectivity between system limits (for inputs and/or outputs). The wastewater system needs to be planned for so that in addressing one system limit, another limit is not exceeded. For example, diversion of wet weather flows to an existing storage or overflow. However, this may be cause it to operate at or beyond its long-term limit. These risks may be foreseeable but require that adequate provision to be made for response when they materialise.*
- *RR #3: considers the risks of not anticipated transforming as required by long term strategies. Risks that arise from transforming are associated with the opportunity cost of not realising the anticipated benefits. The process of transforming the system also carries risks (e.g., from over-investment/gold-plating the system, not fully appreciating the knowledge, values and/or rule gaps that need to be overcome), which must be considered.*
- *RR #4: considers how water corporations respond to .)e.g., a major system shock, a succession of such events and/or rapid and difficult to anticipate change in community values or unpredictable type events (e.g., COVID19). Responses require organisational resilience (as expressed in the resilience principles described above) and the capacity to recreate the wastewater system in a form or identity that is appropriate to the new circumstances.*

Risk assessments provide a robust analysis of issues to support the formulation of interventions and a grounded sense of the priority of the identified risks against organisational or system objectives.

As described in Section 2.2.1, risk equals probability x consequences and can be assessed either qualitatively or quantitatively using a water corporation's corporate risk matrix. This risk ranking, the combined ranking considering both probability and consequence, traditionally drives the priority actions or interventions i.e., the more extreme the combined risk rating, the higher the priority. This approach potentially understates or excludes risks where the probability of occurrence may be uncertain, even if the consequences are major or catastrophic. It also does not consider the fact that the probability and consequences of a given risk may change over time. As a result, it can create a limited and inaccurate view of climate risk. It may also put undue emphasis on risks that are extremely hard to address at the expense of those that could be readily managed.

A useful reference which considers prioritisation of climate change risk is the Climate Compass developed by the CSIRO for the commonwealth government. (https://www.awe.gov.au/science-research/climate-change/adaptation/publications/climate-compass-climate-risk-management-framework). This framework incudes guidance on a modified risk prioritisation approach that could be used separately or combined to account for the uncertainty of climate risks. Climate compass proposes to:

- prioritise based on consequences alone
- prioritise certain types of risk based on your risk appetite and

- prioritise risks that are less certain.

Risk assessments are not intended to be static and should be reviewed periodically in the light of any changes in objectives, experiences from climate change events, and/or new information on climate hazards.

A case study outlining the risk assessment and prioritisation approach used to assess the impacts of flooding at the Melbourne Water Western Treatment Plant is discussed below.

CASE STUDY	
Melbourne Water Coastal climate change impacts on Western Treatment Plant	
What:	Due to the proximity to the Port Phillip Bay an assessment of sea level risk and storm tide impacts on Western Treatment Plant was completed. This included potential response strategies, adaptation options and indicative costs to mitigate against risks. The assessment includes the following tasks: a. Coastal hazard risk assessment b. Risk profile development with assigned score on consequence for each relevant hazard and likelihood c. Risk prioritisation to inform planning and decision making
Outcome:	A “retreat or defend” strategy was developed to manage a mitigate the identified sea level and storm tide risks. This was linked with a sea level rise and storm tide adaptive monitoring program.

4. What can we do about it? Planning and intervening in response to climate change

SECTION SUMMARY: OUTCOMES PROVIDED BY GUIDELINES SECTION 4

What can we do about it?

- We can identify the adaptations which may be needed for potential future climates.
- We can understand the knowledge, values and rules of the interventions which must align for them to proceed.

PRACTITIONER'S GUIDE

This section will help you:

Identify interventions and the associated knowledge, values, and rules to align for an intervention to proceed.

This section provides guidance on identifying interventions that respond to the priority climate change risks and opportunities identified by the water corporation in Section 3. Water corporations use a variety of planning approaches to identify and evaluate future infrastructure requirements to reduce or mitigate risks and achieve objectives, and these may be used or adapted to mitigate climate change risk specifically.

Planning for climate change means planning for uncertainty in multiple dimensions of the plan. In a business there are multiple drivers of change requiring investment; climate change impacts are just one of these. This section focuses only on climate change and how it might be considered in the planning processes for wastewater systems, acknowledging that climate change is only likely to ever be one of many influences on planning and decision-making. The planning process must be informed by broad considerations of the multiple drivers of change which will influence the design and expectations of an aspect of the wastewater system.

This section describes how the planning approaches that a water corporation may use to identify interventions, can consider a changing climate. It also introduces the concept of knowledge, values and rules (KVR), as well as key triggers, decision points and limits for implementation, that must be aligned before interventions are successfully implemented.

As previously noted, a water corporation's overall strategic and tactical objectives for GHG emissions (contributing to climate change) is not a focus of this guideline. However, it is important to identify and assess the merits of interventions which not only address the broad range of climate change impacts on wastewater systems but also those interventions which better contribute to GHG obligations and objectives (e.g., net-zero GHG emissions by 2030 and beyond) and are specifically delivered by wastewater system infrastructure. If the level of GHG emissions from or related to the operation of wastewater system assets are directly increased by climate change conditions, discrete interventions to mitigate these impacts should be considered. One of the assessment criteria for evaluating the merits of interventions should be their relative contributions to GHG emission targets. Further, when building new infrastructure (e.g., new treatment plant) the direct and indirect impacts of climate change conditions on GHG emissions and their influence on achieving GHG emission targets need to be considered. Relevant guidance is provided on this at Section 3.3.5 and in Appendix A.8.

4.1 Planning Approaches

There are a number of planning approaches that may be used to identify and evaluate interventions required to reduce or mitigate risks and achieve the objectives identified in Section 3.1. This section discusses how climate change can be considered within three typical approaches: traditional master planning, scenario planning and adaptive pathways planning (APP). The purpose of this section is not to prescribe or make mandatory a particular process for planning, but to provide guidance on where and how climate change may be considered in planning.

If the rate of change of climate conditions is a 'slow moving' variable(s) then scenario planning or master planning incorporating scenario planning or a simplified version of APP may be sufficient and appropriate. However, APP is highlighted as a more robust and flexible approach to planning for systems augmentation or interventions particularly where there is one or more major future uncertainties in key design parameters influencing the type and quantum of the responses. For example, growth influencing wastewater flows and loads in combination with climate change conditions influencing flows. APP also has strong merit where the number of available interventions to manage the climate change and growth impacts are significant and emerging relevant technology developments offer potential merit in future.

The APP approach indicated here is just one example of how it could be undertaken and represents a case study. Different planning approaches ought to be considered and tailored to the specific context and the decisions to be made. The planning approach selected by a water corporation should also be influenced by available resourcing. Smaller and regional utilities may not be as well placed as other better resourced water corporations or have the necessary skills to implement APP.

4.1.1 Master Planning

Master planning is a long-term planning approach that provides direction on how the wastewater system should be ungraded in the future to adapt to climate change impacts. A master plan is typically based on the most likely future. Uncertainty is accounted for in the wastewater system operating conditions that are used to assess climate change impacts. Master planning is static and generally updated periodically based on reaction to a single condition i.e., increases in peak flows. Master plans are typically based on information available at the time of completing the plan, though more complex master plans may try to account for possible futures that could occur.

The key process of developing a master plan and how the Guidelines can be used to consider climate change throughout the process is shown in Figure 18 below. While there are a range of other factors to consider in master planning this figure focusses on climate change considerations.

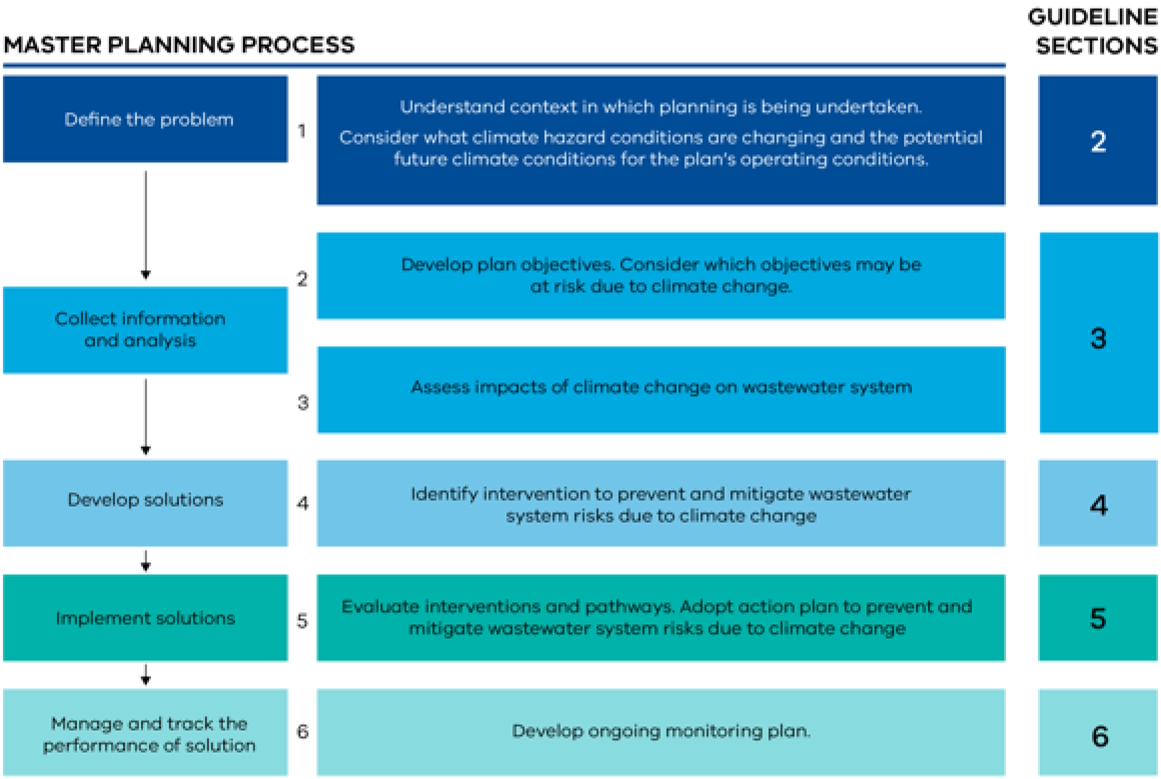


Figure 18: Master planning process in the context of climate change and the Guidelines

4.1.2 Scenario Planning

Scenario planning is a strategic planning method that may be used to make flexible long-term plans that manage the impacts of climate change on the wastewater system. Scenario planning is in large part an adaptation and generalisation of classic methods used by military intelligence. The approach can include elements that are difficult to formalise, such as subjective interpretations of facts, shifts in values, new regulations or inventions. These different combinations of different elements are called "scenarios". The scenarios usually include plausible, important situations and problems that exist in some form in the present day.

Once a number of scenarios are developed, a pathway of actions and interventions from the present to each possible future is constructed. In the case of the wastewater system, these pathways could comprise a series of capital or operational projects and investigations, such as network upgrades and Consideration of alternative technologies. Once a pathway is developed for each scenario, the pathways are reviewed to identify where there are common works. Refer to Figure 20.

Typical steps of scenario planning and how the Guidelines could be used to inform this approach is shown in Figure 19. This typically results in pathways being combined as shown in Figure 20. The result is a flexible plan which aims to keep options for different future scenarios open as far as possible.

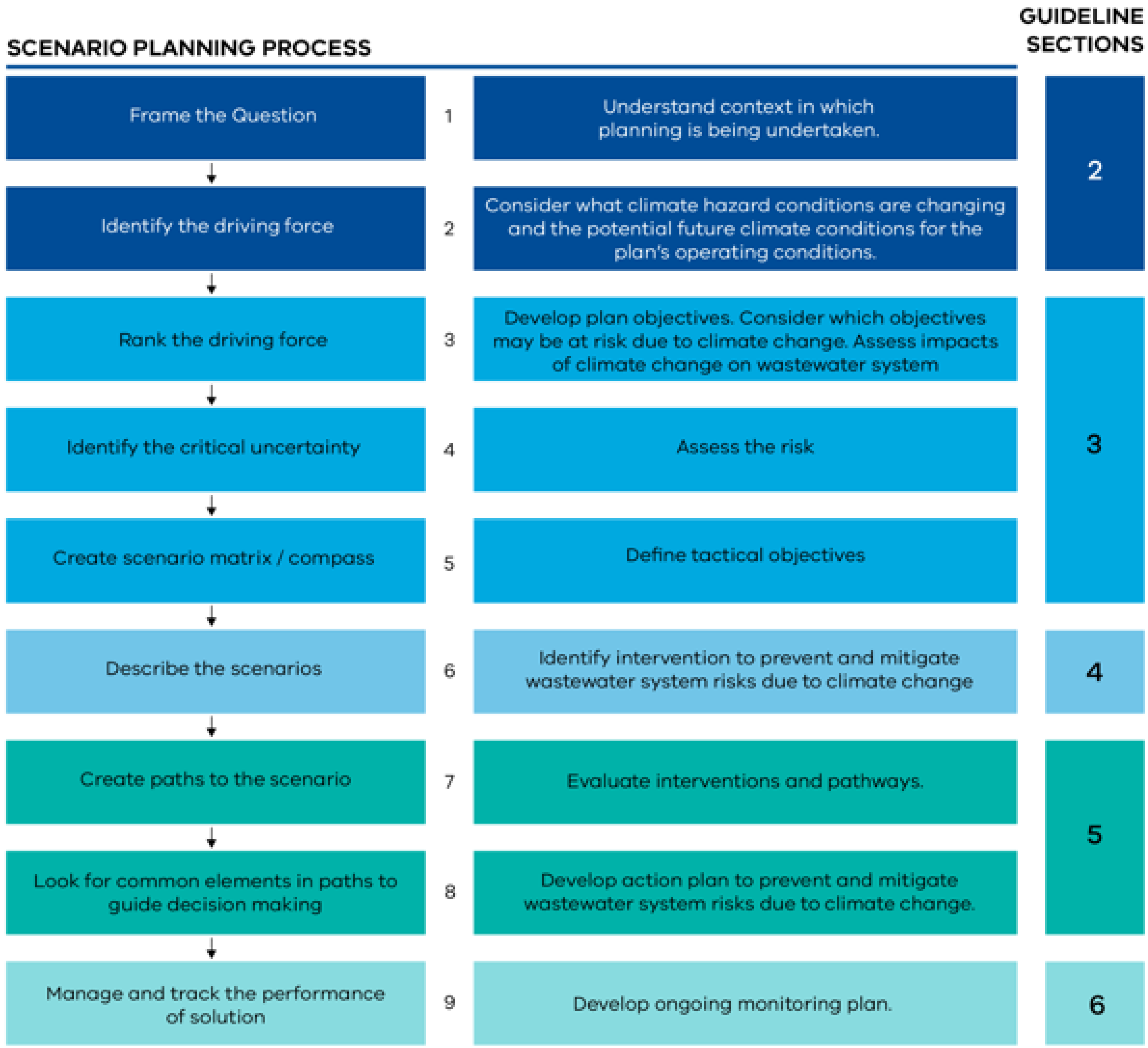


Figure 19: Scenario planning steps

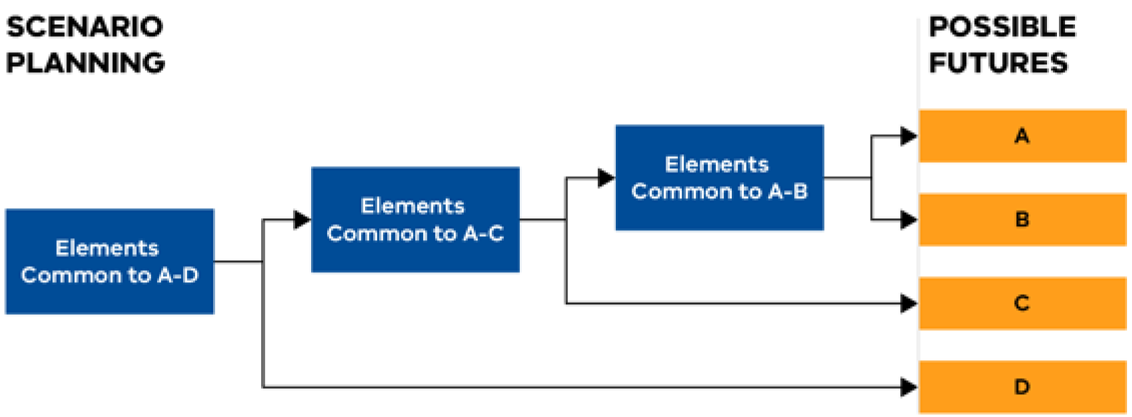


Figure 20**: Scenario planning approach – example for possible futures**

4.1.3 Adaptive Planning

A generic adaptive planning process was introduced in Section 1.6 the Guidelines and its five main questions described in Figure 5. The Guidelines have been developed based on this process.

A particular form of APP is indicated here but modified or alternative forms of adaptive planning could be used. One useful reference is the Dynamic Adaptive Pathways Planning (DAPP) framework proposed for use by the New Zealand Treasury and Auckland Council. There are also many examples with similar APP characteristics especially for flood management planning.

WSAA has established an APP network to connect water corporations with each other to share experiences, information and learnings in implementing .APP This knowledge could be complemented with specialist resources as needed to assist a water corporation in implementing APP.

Real options analysis is an appropriate investment analysis approach linked with adaptive planning. This is addressed in Department of Treasury (DoT) guidance documents, including “Economic Evaluation for Business Cases - Technical Guide, August 2013” as part of DoT’s series of ‘Investment Life Cycle and High Value/High Risk Guidelines series. The following extract from this Technical Guide explains the relevance of real options to adaptive planning.

> *“While risk and uncertainty can be associated with particular costs and benefits (or other important variables) involved in an economic evaluation, it can also be associated with the underlying investment concept or the circumstances surrounding it. This may require an adjunct to the economic evaluation approach to incorporate options which allow the flexibility to defer some of the decision-making until that uncertainty is resolved, including through the use of real options.*
>
> *Real options analysis incorporates flexibility in the investment planning process to allow investments to adapt to uncertainty. It is a useful technique for evaluating project options and planning solutions that are characterised by uncertainty. Real options enable investments to be structured to encompass flexibility at milestone stages.”*

Examples of early efficient investment as part of a real options analysis approach would be early design of a facility, purchase of land and resolution of contractual arrangements to prepare for later major and greatest proportion of investment to build and commission infrastructure when its need is certain. Figure 23: shows the steps where in an adaptive planning process early efficient investments could be made in the manner contemplated by a real options approach. Importantly, in adaptive planning the identification of triggers and each of the key points in the lifecycle decision making process from pre-planning through design, procurement to construction and commissioning sets the basis for real options analysis and identifies the points in time where efficient early investment could be made.

4.2 Intervention Identification and Design

Identification and design of interventions should reflect insights from climate vulnerability and risk assessment. Where features of the wastewater system planning project are highly vulnerable to or at risk from climate change, additional design measures or interventions need to be developed to reduce the risk to an acceptable level. For example, a sewage pumping station is planned to be located in a low-lying coastal area that will be increasingly subject to sea level rise over the planned asset life. Interventions could include relocation, raising its elevation or providing flood defences.

Intervention design considers climate change in three contexts Figure 21:

- What are the climate phenomena to which the design must respond?
- What aspects of the system are affected and how do they respond?
- How does adaptation (or climate-responsive intervention) occur?

In some cases, there will be multiple intervention options through which strategic objective(s) might be achieved.

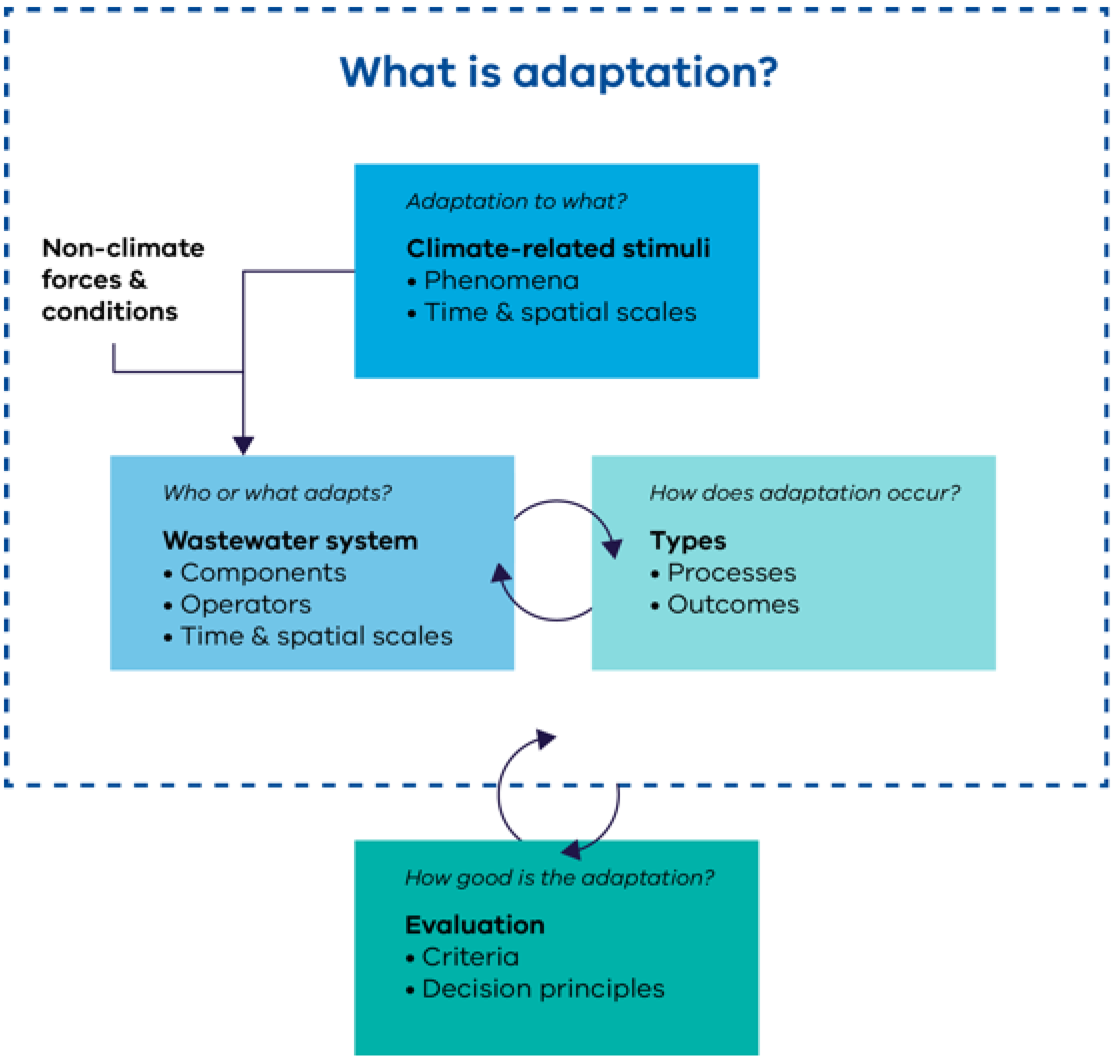


Figure 21: Conceptualisation and evaluation of adaptation to climate change (adapted from Smith et al. 2000)

Potential climate change related risks and interventions for the wastewater system are discussed below. The wastewater system is complex due to the numerous components and the many climate-related parameters that affect the design and ongoing operation of the assets. It is important when assessing and developing interventions that the whole system is considered due to the significant interaction between each component. Water corporations should refer to EPA publications and guidance together with other industry guidance, such as national and international standards, when considering interventions. Additionally, interventions should consider all objectives including climate-related objectives such as net-zero GHG emissions.

4.2.1 Potential Interventions for Sewer Networks

Potential climate change risks and interventions for the sewer network are discussed in Table 16:. The EPA sewerage management guidelines provide a hierarchy of controls for wet weather flows which should be considered in the development of interventions.

Table 16: Climate change risks and potential interventions within the sewer network

Climate Change Risk	Potential Interventions
Extreme heat days	• Protection of existing power supply and communication systems using forced ventilation and air conditions • Increased use of shading

Climate Change Risk	Potential Interventions
Peak wet weather flows (due to extreme weather events)	• Augment network capacity to provide for transfer of peak flows resulting from business nominated target climate change scenario (e.g., RCP8.5) to comply with regulatory objectives (number of overflow events, volumes of wastewater) • Revise standards to reduce stormwater inflows • Implement asset resilience measures to reduce impact of individual component failure. • Emergency storages and overflows at SPS for wet weather flows
Seawater intrusion (due to sea level rise)	• Rehabilitate sewers • Change to alternative systems which minimise infiltration.
Higher variability in climatic conditions increasing soil corrosivity	• Change pipeline or manhole structure material • Adopted more flexible corrosion resistant pipework
Storm / extreme weather	• Investment in power supply resilience (e.g., on-site generation, increased system storage capacity) • Remote operation of facilities • Contingency and emergency event management plans
Risk of inundation	• Consideration of the type of sewer network asset (e.g., gravity or pressure) and location during asset planning stages, ensuring critical assets are protected against predicted flooding and coastal recession. • Consideration of the location of the sewer asset during asset planning stages, ensuring critical assets are where feasible, located outside the predicted flooding and sea level zone. • Upgrading of discharge structures from gravity to pumped. • Provide barriers (e.g., berms, lining of ponds) • Sufficient bunding and drainage around infrastructure to protect assets. • Structural design requirements, e.g., in near-coastal areas experiencing rising groundwater levels associated with sea level rise, review the need to strengthen structural supports including additional or deeper piling. • Physical relocation of existing critical assets to suitable higher ground.
Sewer Spills	• Use the outputs of the assessment to reframe proactive asset management programs including for sewer asset condition inspections (for service condition, potential for blockage), sewer cleaning (e.g., root cutting) and sewer renewals.
Increased odour and corrosion (due to warmer temperatures and reduced flows during periods of drought)	• Install new, or augment an existing ventilation system • Install new, or augment an existing odour control facility • Provide corrosion / odour dosing within the system • Replace assets with corrosion resistant materials i.e., corrosion resistant liners in corrodible sewers, glass reinforced pipe (GRP) liners in maintenance holes • Design system to minimise system drops • Design system based on laminar flow conditions • Where feasible design system to minimise pressure sewer discharge to gravity sewer, where required, ensure system is designed for the predicted odour and corrosion rates
Bushfires	• Separate pump stations from bushfire prone vegetation either by appropriate siting or creation of defendable spaces. • Install critical equipment such as switchboards in fire rated buildings • Consider installation of fire-fighting system around critical sewer pump stations • Provide for resilience of power supply by undergrounding powerlines or making provision to power by mobile generator.

Climate Change Risk	Potential Interventions
Increased design conditions (to allow for the predicted conditions)	• For new equipment update specifications to reflect the climate data projections, for example: ambient temperature and number of days over xx rated equipment temperature per year; relative humidity, and changes to corrosive environments.

4.2.2 Potential Interventions for Wastewater Treatment Systems

Potential climate change risks and interventions for wastewater treatment systems, recycled water and biosolids are discussed in Table 17.

Table 17: Climate change risks and potential interventions at WWTPs

Climate Change Risk	Potential Mitigation Measure
	SITE RISKS
Storm / extreme weather	• Investment in power supply resilience (e.g., on-site generation, increased system storage capacity) • Remote operation of facilities • Design of buildings to withstand storm / extreme weather events • Where there is a risk to site access due to the impacts of storm/extreme weather, provide more than one access road into the plant • Contingency and emergency event management plans
Bushfires	• Separate treatment plants from bushfire prone vegetation either by appropriate siting or creation of defendable spaces. • Install critical equipment such as switchboards in fire rated buildings • Consider installation of fire-fighting system around critical sewer pump stations • Provide for resilience of power supply by undergrounding powerlines or making provision to power by mobile generator and/or designing for a low power treatment mode.
Increased odour and corrosion (due to warmer temperatures and reduced flows during periods of drought)	• Install covers over odorous areas and ventilate to a new Install new, or augment an existing odour control facility • Provide corrosion / odour dosing within the system • Replace assets with corrosion resistant materials i.e., corrosion resistant liners in corrodible sewers, glass-fibre reinforced plastic liners in maintenance holes • Design system to minimise localised areas of corrosion
Extreme heat days	• Provide design allowances, which will likely require additional equipment, such as additional air conditioners for electrical switch rooms, and blowers to provide peak demands on extreme heat demand days. • If the increased ambient temperature is predicted to accelerate biological reaction rates, allowing more efficient use of process tankage there could be an opportunity to re-rate existing plants and deferring plant capacity augmentation, or reducing tankage requirements for new plant upgrades.

Climate Change Risk	Potential Mitigation Measure
Risk of inundation (Flooding and Sea Level Rise)	• More consideration of the location during asset planning stages, ensuring critical assets are protected against flooding and coastal recession under worst-case climate change scenarios, e.g., outlets into tidal zones. • Locate future assets outside the predicted flooding and sea level zone. • Physical relocation of critical assets to suitable higher ground. • Upgrading of discharge structures from gravity to pumped. • Provide barriers (e.g., berms, lining of ponds) • Sufficient bunding and drainage around treatment plants to protect assets. • Structural design requirements, e.g., in near-coastal areas experiencing rising groundwater levels associated with sea level rise, review the need to strengthen structural supports including additional or deeper piling.
Risk of inundation	• Consideration of the type of sewer network asset (e.g., gravity or pressure) and location during asset planning stages, ensuring critical assets are protected against predicted flooding and coastal recession. • Consideration of the location of the sewer asset during asset planning stages, ensuring critical assets are where feasible, located outside the predicted flooding and sea level zone. • Upgrading of discharge structures from gravity to pumped. • Provide barriers (e.g., berms, lining of ponds) • Sufficient bunding and drainage around treatment plants to protect assets. • Structural design requirements, e.g., in near-coastal areas experiencing rising groundwater levels associated with sea level rise, review the need to strengthen structural supports including additional or deeper piling. • Physical relocation of existing critical assets to suitable higher ground.
Increased design conditions (to allow for the predicted conditions)	• For new equipment update specifications to reflect the climate data projections, for example: ambient temperature and number of days over xx rated equipment temperature per year; relative humidity, and changes to corrosive environments.
RISKS TO WASTEWATER TREATMENT	
Peak wet weather flows (due to extreme weather events)	• Augment treatment plant capacity to provide full treatment of peak flows. For lagoon-based plants this may only require the augmentation of the inlet pump station, inlet screens, and plant hydraulics. If there is sufficient lagoon capacity, the works may not be significant. • For mechanical plants, where the peak flows are significant, full treatment of all flows can result in a large treatment facility and may not be economically efficient • Optimisation of flow balancing and wet weather bypass treatment to provide the required level of treatment to meet target requirements. This could include construction of bypass infrastructure to either store peak wet weather flows for later return and treatment through main treatment process or provide wet weather treatment to peak flows above the capacity of the main treatment process.
Seawater intrusion on treatment process	• When high salinity causes nitrifier inhibition, there are limited options to provide treatment to ensure compliance with EPA licence requirements. Where a plant discharges immediately following treatment, the effluent, high in ammonia, could be diverted to a wet weather storage if available, and returned to the process once the high salinity event has passed, with the return flowrate sufficient to ensure the blended feed does not inhibit the process. • Change to alternative systems which minimise infiltration. • Accept and adjust STP treatment technologies used.
Seawater intrusion on corrosion	• Progressively replace assets with corrosion resistant materials.
BIOSOLIDS TREATMENT	

Climate Change Risk	Potential Mitigation Measure
Biosolids treatment – sludge drying • *Higher variability in climatic conditions, particularly in wet and dry years, impacts on the sludge drying area required*	• To reduce the variation in sludge drying rates in between dry and wet years, additional ‘turning’ of the drying sludge can be undertaken in wet years to increase the drying rates to a rate more similar to the dry year average. • Solar drying pans can reduce the impact of rainfall on sludge drying rates • Alternatives to sludge drying can be considered, noting that the EPA’s preference is to minimise the reliance on air drying of solids. • Monitor inferred net drying rates as a function of solids loading rates and link with trends in key climate change conditions (local/regional rainfall events and temperature). Adjust drying area requirements based on the changed drying rates.
RECYCLED WATER STORAGE AND REUSE	
Peak wet weather flows (due to extreme weather events)	• Assess recycled water storage strategy to provide storage for wet years and more recycled water in dry years • Assess the storage capacity and weather conditions to maintain DW2.8 condition • Consider alternatives to open winter storages such as aquifer storage and recovery • Diversification of recycled water users, for example, to recycled water demands less impacted by climatic conditions, such as indoor uses, greenhouse horticulture, industrial reuse.
Seawater intrusion	• Wet weather discharge to inland waterways • Diversion of recycled water uses • high salinity recycled water could be blended with alternative water sources • Treatment processes such as RO could be introduced to reduce salinity levels
Asset integrity and durability	
Higher variability in climatic conditions increasing soil corrosivity	• Change pipeline or manhole structure material • Adopt more flexible corrosion resistant pipework

4.2.3 Bushfires

Bushfire protection measures should be developed to accommodate changes in exposure that arise from climate change. Interventions would build on business-as-usual approaches that incorporate:

- Where possible, locating fire-sensitive infrastructure in areas of lower bushfire risk (i.e., away from bushfire-prone vegetation, in areas where a fire would approach the infrastructure downhill rather than uphill).
- Separation of the infrastructure from bushfire-prone vegetation to create a defendable space. This may involve the clearing of trees and understory vegetation to prevent direct flame contact, lower radiant heat exposure and reduce exposure from ember attack.
- Safe access: access roads/tracks should enable safe egress by personnel located at the wastewater system facility and safe access and egress by fire services.
- Provision of water supply and utilities: where possible, access should be provided to water that is suitable for fire suppression. This may include overhead sprays that douse the infrastructure with water to prevent overheating or ignition. Electricity and any gas services must be located so that they do not add to the risk faced by fire services. If the facility is critical to wastewater services, it may be necessary to take measures to ensure the continuity of power supply if there is a fire.
- Emergency management arrangements: fire services should be made aware of the wastewater facility, its criticality and the protection measures that are in place.

- Resilient design and construction: critical fire sensitive equipment (e.g., switchboards) should be located (including in structures designed for the bushfire attack level exposure (after AS3959-2018 *Construction of buildings in bushfire pone areas*, Standards Australia, 2018).

While bushfire-related climate conditions would be considered in designing these interventions, climate change, as such, may not be directly considered. Changes in potential fire intensity and radiant heat exposure potentially could be considered in planning defendable spaces and resilient design.

4.3 Knowledge, Values and Rule (KVR) Framework

When thinking about future key decisions it is important to understand the context in which decisions are made and what might limit interventions and provide resistance to change. Knowledge, values and rules (KVR) is a framework to support decision making around adaptation (see Figure 22 below).

The KVR framework assists with identifying whether interventions are available now, and if not the timing of when they may be available in the future. In this way the KVR framework maintains consideration of interventions which could contribute to achieving the long-term objective(s) but are not available now because of the current barriers to implementation. This is particularly important where interventions may be necessary because the currently available options are not capable of achieving a strategic objective(s) or a limit has been reached requiring adoption of materially different option(s).

The KVR framework identifies and addresses issues by recognising barriers to implementation of an intervention option and its readiness for adoption at key decision points.

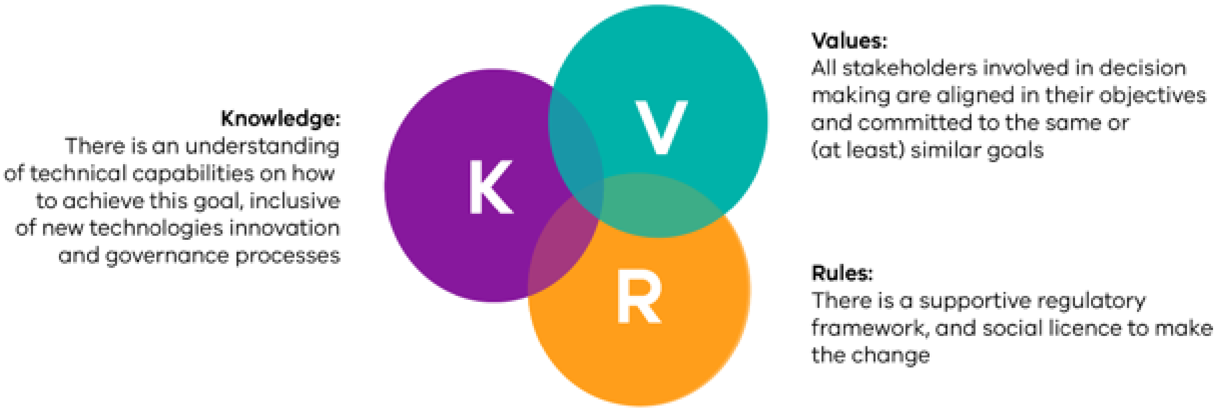


Figure 22: Overlap of KVR (intersection) – needed for successful adoption

A KVR analysis of interventions provides a valuable starting point for effective decision-making processes. Where knowledge, values and rules overlap there is a “sweet spot” for viable decision making. The outputs of the KVR analysis then assists with identifying what actions could be undertaken, and the associated timeframes, to allow a particular option to become available in the future. A summary of the meaning and concepts of KVR are provided in Table 18 below.

Table 18: Description of knowledge, values and rules (KVR) as applied within this adaptive pathway process.

KVR Framework	Key questions	Example
Knowledge of options and their implications. *This is both evidence-based knowledge and experiential knowledge. Our understanding of how we implement the intervention, including the technology it requires, and potential limits and risks. This can also include social or customer/community orientated knowledge, quantitative or qualitative.*	• Do we know what to do? • Do we know how to do it? • Do we know what we will achieve by taking an action? • Will there be any unintended benefits or adverse effects?	• Modifications to the wastewater treatment plant discharge to the waterway may be required – lack of knowledge on receiving waterway to determine whether discharge will have beneficial or negative impact.
Values to assess the options.	• Do our stakeholders (community, internal	• Strengthening resilience to climate change or decarbonising the wastewater system may be

The set of ethical principles that determine the way people select actions and evaluate events that will support action to achieve a desired outcome. This considers what is important now and in future, for all stakeholders including the environment.	stakeholders) want the intervention? • Is it within our social license to operate?	fundamental to stakeholder engagement and achievement of the social licence.
Rules that enable implementation. *These are both rules-in-use (norms, practices, habits, heuristics) and rules-in-form (regulations, laws, directives through to business rules) that affect what we can and can't do.*	• Does current legislation, policy or standards align with the intervention? • Do we need to change the rules to implement the intervention?	• Modifications to a pump station emergency overflow may be required that should be in accordance with the Environment Protection Act 2017 and GED.

The KVR outputs are used to develop an implementation plan for each intervention to be considered in the development of a possible future pathway, see Section 5.1. The intervention is not considered available for implementation until the knowledge, values, and rules are all aligned, as shown in. Figure 23: below. Therefore, the implementation timeline is made up of the KVR actions (which includes some feasibility and preliminary design activities), followed by design and construction timings for the intervention to be operational.

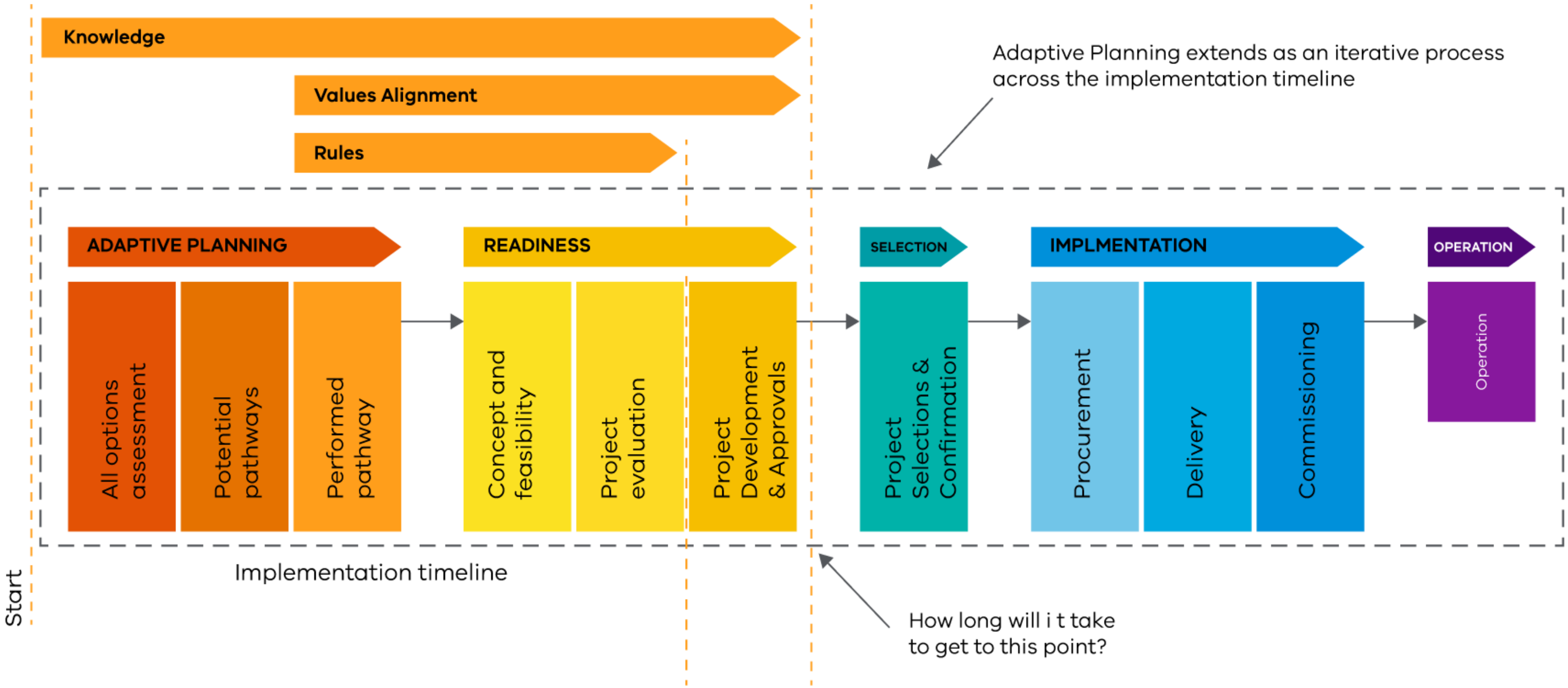


Figure 23: Example of KVR alignment required for implementation of an intervention.

5. How can we implement the plan? Making decisions to support implementation

SECTION SUMMARY: OUTCOMES PROVIDED BY GUIDELINES SECTION 5

How can we implement the plan?

We can keep the investment pathways open until decisions must be made.

We can define the system limits, decision points and triggers to enable timely implementation of the plan.

PRACTITIONER'S GUIDE

This section will help you:

Identify triggers, decision points and limits to define and assess future pathways.

This phase seeks to provide guidance in decision making to implement a plan. It includes grouping interventions into pathways, assessing the pathways and developing an action plan. Governance processes that should be established to support funding and implementation of an adaptive plan to manage the impacts of climate change and ensure all service objectives and obligations continue to be met, are also discussed.

5.1 Possible Future Pathways

A resilient wastewater system is one that is prepared for, able to withstand and then recover and learn from disruptive trends or events. A resilient system would continue to progress towards desired outcomes, including delivering the functions and features outlined in Section 4, even as climate changes.

Creating a resilient wastewater system requires change. Resilient assets are delivered through decisions, governance and organisational culture that offer different perspectives on risk and opportunity to current "business-as-usual" (BAU) processes.

Intervention pathways are the sequence of interventions required where there are progressive responses to climatic and/other drivers of change and/or steps towards the objectives. Intervention pathways exist on a spectrum of complexity, with multiple pathways typically identified comprising various mixes of interventions including to respond to climate change impacts. There should be no fixed pathway identified but initial interventions identified, and options and pathways kept open for the future. Adaptive planning implies progressive implementation of infrastructure and non-infrastructure interventions. In some cases (e.g., for progressive development of defences to protect coastal wastewater treatment infrastructure from sea level rise) the sequencing of interventions would likely be influenced by the extent and rate of climate change actually experienced.

Intervention pathways are developed in consideration of the mix of interventions required to achieve the objectives and the implementation timeline for the interventions defined in the KVR analysis.

An example adaptive pathways output, based on a suite of interventions, is shown in Figure 24:. In a master planning approach, there would be only one pathway to consider. Section 5.2 describes how systems limits are preceded by an implementation point where the intervention becomes available, a decision point where the water corporation commits to an intervention and a trigger when interventions become effective and the KVRs align. These points are shown on the figure below to demonstrate how pathways could be developed to achieve the objective and manage the impacts of climate change.

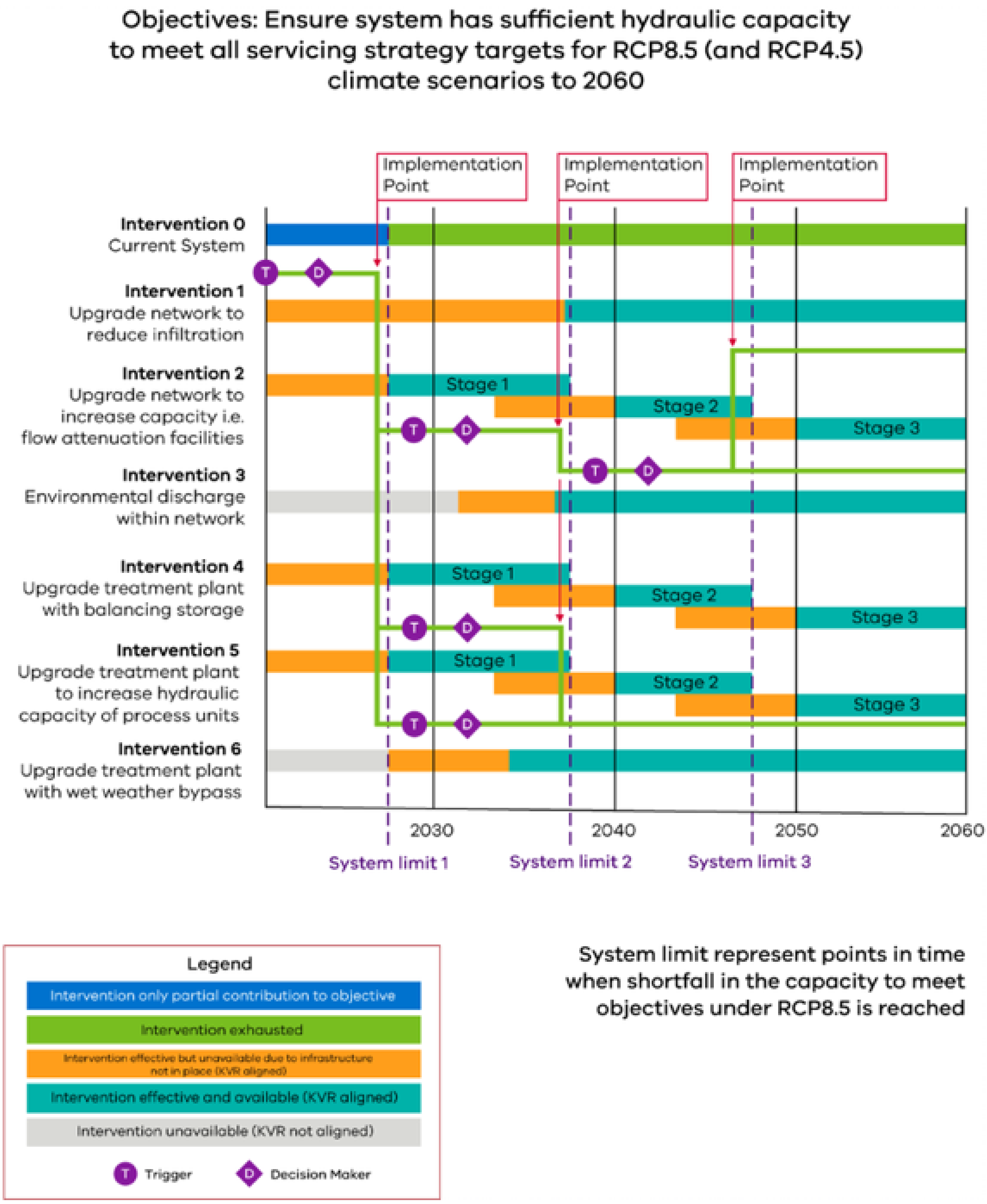


Figure 24: Generic adaptive planning pathways example for illustrative purposes only – (all possible pathways are not shown for clarity)

5.2 Triggers, Decision Points, Limits

Consideration of triggers, decision points and limits should be undertaken in the context of the mix and order of interventions within a pathway and to incorporate the KVR implementation plan for those interventions, refer to Section 4.3.

Figure 25 shows how triggers and decision points within an existing system can be developed.

Identifying trigger points for different categories of asset classes is a key requirement in responding to and adaptively managing the uncertainties of climate change impacts, especially the deep uncertainty associated trajectory of GHG emissions and the difficulty of estimating the impacts. There may be a future opportunity to streamline the processes described herein. The examples provide guidance now and for later streamlined processes.

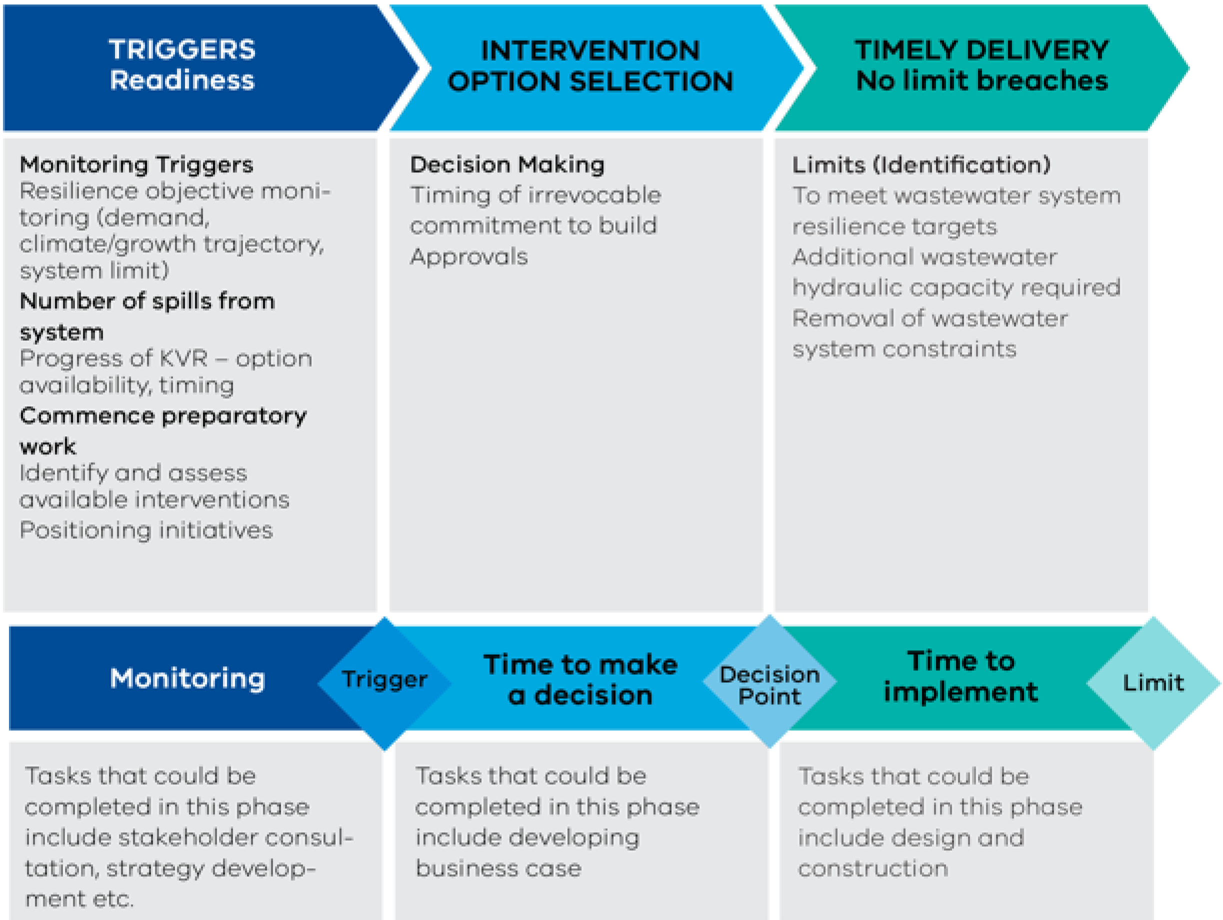


Figure 25: Development of the trigger and decision point with relation to the system limit

Referring to Figure 25 and reading right to left through the graphic:

- *An intervention once implemented will have a limit with respect to achieving a strategic objective(s):* The limits of each intervention are specified as either a 'hard' or 'soft' limit. A 'hard' limit indicates that the intervention is exhausted, and a completely different approach or technology needs to be adopted e.g., sea level rise is limiting wastewater treatment plant's ability to discharge to the bay requiring a different approach. A 'soft' limit can be overcome through implementation of the same approach or technology that has already been agreed and adopted e.g., adding additional biological reactor volume of the same technology to increase capacity. Some interventions may only partially achieve an objective. Identifying the limit(s) of each intervention provides an understanding of when a decision needs to be made to progress the pathway.
- *A decision point leads a system limit:* The decision point defines when action should be taken, before a system limit is reached, to continue with the current intervention type or adopt another intervention type and implement necessary works.
- *A trigger is a point in time sufficiently before a decision needs to be made:* The trigger instigates action in time for the necessary implementation planning and preparation including assessment and confirmation of which intervention type(s) and future pathways are most appropriate. Triggers define the key relevant parameters to be monitored that forecast an approaching intervention limit, and decision point, and specify a threshold value for the parameter monitored. That is, the concept of a trigger relates to a system limit being reached e.g., inability with existing system infrastructure and operation to satisfactorily manage climate change impacts within agreed objectives. These limits could also relate to actual or potential physical impacts, such as changes in sea level, forecast flood levels, temperature risk or change in water resource availability or to changes in values or

rules that are linked to climate change e.g., a willingness to accept full potable reuse of recycled water due to climate change induced water scarcity.

Additional notes are provided in Figure 25 that may assist with framing how these key terms relate to each other.

Each of the interventions may have differing decision points to allow the intervention to be implemented before the system limit is reached. By developing the limits, decision points and triggers for the interventions, the adaptive pathways can then be developed to ensure the system is able to continue meeting the objectives within the system limits across the planning horizon.

Referring back to Figure 25, the trigger is determined by two factors:

1. The time it takes to align KVR so that there is confidence in proceeding with implementation of the intervention (this is the decision point)
2. The time it takes to implement an intervention (from design, construction to operation such that the system limit is not met).

For example, if the system limit is projected to occur at 2042, and the intervention has a KVR period of 15 years, and a D&C period of 5 years, the 'trigger' to progress the KVR actions appears in 2022. For interventions that require significant KVR alignment, the trigger for action may be 'now' so that those options can be 'ready' in time to make a decision, implement an intervention and avoid reaching a system limit.

There may be additional triggers within the KVR implementation timeline, refer Section 4.3, to ensure adequate progress is being made towards getting the intervention 'decision ready'.

5.3 Assess the Pathways

This section seeks to provide guidance on assessing the advantages (the benefits) and disadvantages of an intervention or pathway option. This includes assessing how well the pathway addresses climate vulnerabilities/risks and how it performs against other financial and/or non-financial criteria.

Improvements in the resilience of a system decreases the impact of external shocks on the path of outcomes, and therefore provides greater certainty in outcomes.

Pathway evaluation may be undertaken using typical business assessment methods such as multi-criteria assessment (MCA) and benefit-cost analysis (BCA). Both require input of a net present value (NPV) evaluation of the pathway.

Multi-criteria assessment

MCA is a process that consists of setting indicators/ criteria that align with business objectives. to assess the pathway or option against. Indicators may be given a weighting. The outcome of the assessment will give an overall score. The highest scoring option being the preferred intervention. MCA can manage qualitative and quantitative data. It works well where the benefits of an intervention are well understood. The drawback of MCA is that social, environmental and operational factors are typically assessed qualitatively rather than quantitively.

Benefit-cost analysis

Economic analysis, particularly BCA, is a powerful way of demonstrating a case for investment as it explicitly seeks to show that the benefits of a management decision exceed its costs over some time horizon. BCA provides a clear way of demonstrating value for money by quantifying benefits (the advantages of making the change) and costs (what is sacrificed to make the change) in monetary terms wherever possible, and therefore allowing like-for-like comparisons.

BCA includes market and non-market impacts. Market impacts refer to costs and benefits that generally involve a clear transaction and market price. Non-market impacts refer to costs and benefits that do not necessarily have a clear transaction price. As such, BCA incorporates the value that the community or individuals place on social, environmental and economic outcomes.

The case study below is an example of a substantially less expensive intervention being adopted which provided greater environmental and community benefits. This outcome would not have eventuated had a BCA not been used.

The range of socio-economic costs and also the economic value of actions undertaken/interventions implemented that fall on residential and commercial customers, the public water sector, and the broader community are shown in Figure 26: Examples of socio-economic impacts.

Figure 26: Examples of socio-economic impacts

BCA can also apply probabilistic methods to consider uncertainty. These methods could include the probability of a climate change event occurring, the probability of the impacts of that event being realised and analysis of compounding risk scenarios. This is of particular value when considering interventions and pathways to prepare for low likelihood, extreme consequence events. It is the preferred approach by economic regulators such as the Essential Services Commission and by economic managers including the Victorian Department of Treasury and Finance.

In summary, the key outputs from the BCA are:

- Net present value (NPV)—the difference between the discounted or present value (PV) of benefits and costs. A positive NPV indicates that the project delivers net benefits to the community and is therefore economic. A negative NPV is also a net present cost (NPC).
- Benefit–cost ratio (BCR)—the Present Value (PV) of the quantified incremental economic benefits (financial, social and environmental) divided by the PV of the quantified incremental costs (e.g., project capital and operating expenditure, plus other investments required to realise those benefits).

The above is supported by real options analysis as discussed in Section 5.1. A BCR greater than 1 for earlier investment initiatives (e.g., undertaking early design, buying land or equipment) is also relevant to the overall economic assessment for justifying early investment. This would take account of the probability of the need for the main investment and its timing, and the disbenefits if the main intervention response is delivered too early or too late.

CASE STUDY *Kilmore Environmental offsets (Goulburn Valley Water)*	
What:	• The Kilmore WMF (Wastewater Management Facility) supplies and stores recycled water for irrigation purposes. Due to projected population growth a significant plant augmentation was required. Through extensive consultation with EPA rigorous cost benefit analysis and ecological risk assessment an offset scheme was considered as it would allow the facility to commence discharging recycled water to the local creek instead of having to expand its current storage and irrigation capacity. To negate the impact of the discharge to water quality, the facility offset the increased nutrient and pollutant loads within the catchment. The increased pollutant and nutrient discharge from the facility would therefore be counterbalanced by the improved environmental outcome of these offset works. (Reference: Kilmore Environmental Offsets, Clearwater regional case study).
Challenges:	• The capital cost of winter storage for recycled water use during the summer irrigation period is expensive
Climate change considerations:	• This same approach could be adopted where climate change limits or temporarily reduces the extent of irrigation of recycled water use and to minimise the extent of storage in wetter years. With more variable climatic conditions the size of the winter storage to contain the recycled water produced increased compared with previous estimates. Discharging recycled water in excess of the existing winter storage and properties utilising the reuse water provides a more reliable recycled water use.

5.4 Action Plan

Once the preferred pathway is identified through the assessment described in Section 5.3, and an action plan is developed. Implementation of the action plan is critical to making progress and informed decisions. A summary of what should be included in an action plan are outlined below. An example template is provided in Table 19. The template includes an 'owner' column, which provides governance of the plan to encourage ownership of the actions through the planning process.

Action plans should identify:

- Specification of the physical infrastructure, operational and policy initiatives that would need to be undertaken in the short- term as a first step on the initial pathway identified. These would typically be specific infrastructure (and non-infrastructure initiatives implementable with certainty for the initial 5-10 years. These would be projects or programs justified for prudency and cost efficiency meeting the ESC's PREMO framework requirements for a water corporation's pricing submission, to address climate change risks). [PREMO = Performance, Risk, Engagement, Management and Outcomes, the basis of the ESC's economic regulatory assessment framework].
- Specification of the mix of interventions to address the impacts of climate change over a 25-to-50-year period that should feed into long-term business strategies.
- Suite of future limits, decision points and triggers (based on current knowledge).
- KVR activities that need to be pursued to support implementation of future interventions and further development of the adaptive plan

Table 19: Action plan template

Action Description	Indicative Trigger	Indicative Decision Points	Owner
Intervention #1			
Required actions to pursue, understand or achieve an outcome e.g., engaging with stakeholders, encouraging revisions to business strategy framework, more detailed assessment to inform decision	This could be based on a design parameter or external factors e.g., increase in peak flow, change in community perception, change in legislation etc.	This could include adoption of other future intervention where the KVR is currently not aligned	e.g., Asset Planning Manager

5.5 How to make a case for investing in climate adaptation measures – development of a business case

Climate change is one of many risks for water corporations that must be considered and responded to. Climate change risks should not be considered in isolation and should be integrated into existing risk assessment and decision-making processes.

Current risk-based approaches should be reviewed and modified to reflect how the climate change impacts identified in Section 4 should be incorporated into decision processes, business cases and Board deliberations. This should include how corporate risk profiles and declared risk appetites might need to be modified to account for climate change risks.

Integrating climate change risk will look different for each water corporation in line with their individual investment decision-making framework. A key-element likely to be common to all, is the development of a business case to provide justification for proceeding with interventions for the preferred pathway and the associated action plan. Key components that should be used within or to support the business case include:

- **Decision and Implementation Timeframe**: This would map out the process in Figure 23 and Figure 25 emphasising the value of differences in available timeframe to implement a decision, and the design life of the asset, as key issues in dealing with the uncertainties of climate change impacts.

- **Expenditure Impacts:** the costs associated with implementing interventions required to address climate change impacts should be identified (e.g., costs associated with capacity upgrades and renewals; increased renewal and maintenance expenditure for addressing elevated sewer break rates). These costs could be capital or operational expenditure. As described in Section 5.3, NPV's should be completed during the assessment of the pathways. If a BCA is complete this will also quantify benefits and costs in monetary terms, enabling demonstrating of value for money. This information in monetary terms should be used to outline the expenditure impact to the business and support the decision to proceed with the recommended climate adaptation measures.
- **Value Measurement:** Identification and where possible, quantification of the value of the interventions and pathway should be included in the business case to justify the investment decision. A water corporation should determine how it measures value by defining criteria that align with the business objectives. As highlighted in Section 5.3 a BCA incorporates the value that the community or individuals place on social, environmental and economic outcomes and thereby measures and demonstrates the value of the investment decision.
- **Explicit Trade-Offs:** Trade-offs may need to be made for managing climate change impacts in capital constrained environments. The APP approach helps make short-term decisions that should provide water corporations the greatest flexibility to adapt to climate change impacts. The APP approach is suited to a capital constrained environment where an insight into the long-term strategy will provide a strong basis for making an initial investment decision. Key consideration within the Guidelines that should be considered in this situation are:
  - Risk prioritisation approach (Section 3.4) – this process should be adapted to suit the businesses specific businesses risk appetite, and the level of consequence and uncertainty of risks that the business is comfortable with.
  - KVRs (Section 4.3) – this framework allows consideration of interventions that may not be available now but will assist in achieving the strategic and tactical objectives. This allows water corporations to understand long-term investment decisions that may need to be made while understanding the best short term investment decisions that provide the greatest future flexibility.
  - Sequencing of interventions and pathways development (Section 5.1) – during this step water corporations can sequence interventions based on specific understanding of available capital in the short, medium and long-term.
  - Business assessment methods (MCA and CBA) (Section 5.3) – the basis of progressing a pathway or intervention should be based on a solid understanding of the potential advantages or benefits that could arise through the implementation.
- **Success Measures:** Success should be measured against achieving business objectives. Section 3.1 describes an approach for developing quantifiable tactical objectives specific to climate change impacts on the wastewater system. The tactical objective should have associated metrics which the interventions progress toward. The link between the proposed intervention and objective should be included within the business case as justification for making the investment decision. Identification of no-regret decisions should also be included to demonstrate that the investment decision is justified under a range of future climate scenarios. This could be understood by undertaking a sensitivity analysis during impact assessment phase discussed in Section 3.3.2.
- **No regrets decision-making:** is an approach to management and decision making that involves erring on the side of caution and planning well in advance, given future uncertainties. This can be linked with implementation plans in adaptive systems planning. A "no-regrets" approach and actions are sometimes also defined as those that can be justified from an economic, and social, and environmental perspectives whether natural hazard events or climate change (or other hazards) take place or not. Actions which have multiple benefits including addressing climate change impacts should be a priority. The merits and materiality of benefits which primarily or solely address climate change impacts need to be justified. This approach is also linked with the benefits of a real options analysis (refer Section 5.1). .

Tracking of success and performance in managing climate change impacts should be included in the monitoring plan discussed in Section 6.

6. How is it working? Monitoring drivers and triggers and review effectiveness of plan

SECTION SUMMARY: OUTCOMES PROVIDED BY GUIDELINES SECTION 6

How is it working?

- We are monitoring the rate of change of the climate and the effectiveness of the interventions already implemented to identify whether the plan is being confirmed or needs to be modified.
- We are monitoring the system limits, decision points and triggers to instigate the next steps of the plan.
- We are monitoring the external and internal drivers for adaptation and the development of knowledge relating to wastewater systems and climate.

PRACTITIONER'S GUIDE

This section will help you with the:

Specification of monitoring regimes.

Adaptive planning and risk management processes include explicit commitments to ongoing monitoring, evaluation and adjustment of interventions and risk treatments. A monitoring and review plan should be developed to help monitor progress against objectives and the parameters related to triggers, decision points and limits of the plan. The monitoring and review plan should identify the key questions to be asked in review and evaluation of the action plan and its implementation, as well as the monitoring required to answer these questions. Each phase of the adaptive planning process used to frame the Guidelines should be considered to develop a monitoring and review plan.

The following section discusses the ongoing monitoring and review required linked to each step of the adaptive planning process to support adaptive responses to climate change within wastewater systems.

To support the monitoring reviews outlined in this section there are also more generalised learning and feedback loop frameworks and tools indicated in literature which may be of complementary value. One example drawn from literature, shown in the diagram below, is a Triple Loop Learning framework (incorporating single and double loop learning) developed by others. This involves bringing back learnings from analysis and effects of actions taken back into the planning process/cycle.

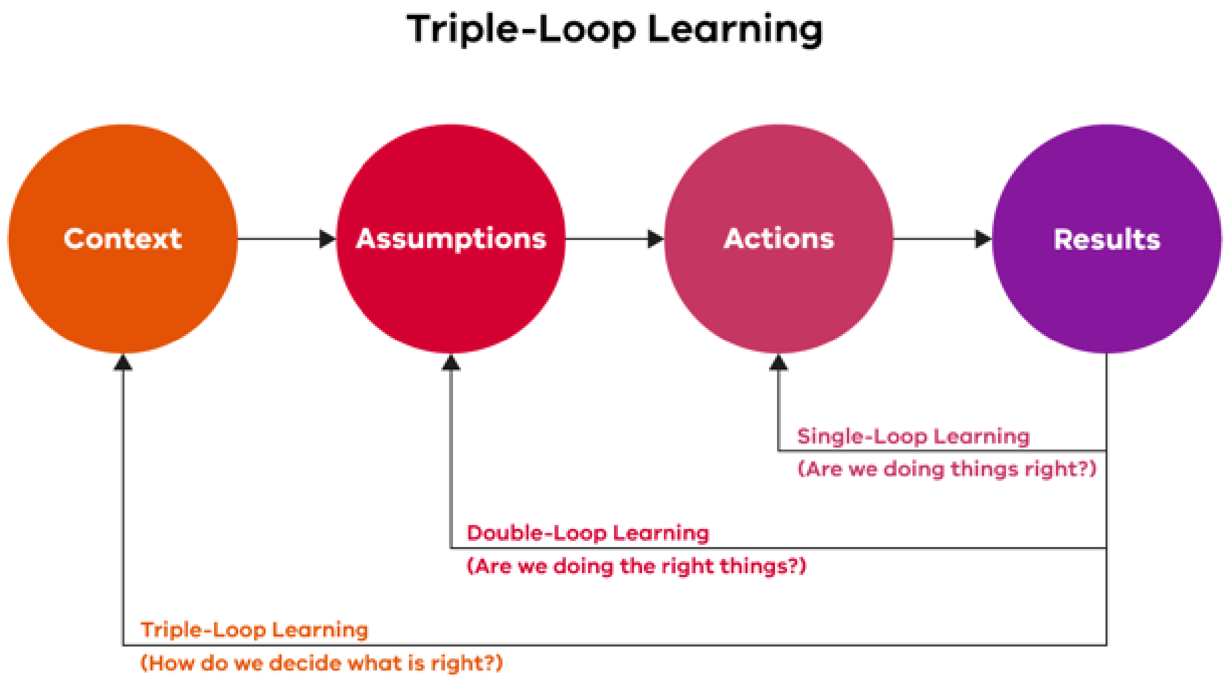


Figure 27: Triple-loop Learning Model

6.1 Monitoring the climate change context

This section refers to monitoring the context for managing climate change. The context should be monitored regularly and includes monitoring for:

- changes in the external legislative, regulatory and policy context for climate change
- changes in internal climate risk governance and risk appetite
- changes in climate and projected climate hazard conditions.

When changes are identified, revisions or adjustments may be needed to the water corporation's plans for climate adaptation. For example, the introduction of new emissions reduction obligations may require modifications to planned or existing treatment plant infrastructure to reduce fugitive methane emissions. The introduction of explicit climate risk disclosure requirements may require changes to climate risk governance and management processes that propagate through planning for and management of the wastewater system.

Monitoring for changes in climate and projected climate hazard conditions applicable to the wastewater system should include:

- **Climate conditions:** data on the eight key types of climate condition that potentially influence wastewater systems, refer to Section 2.3, should be gathered by the water corporation or accessed from public records. This information will provide important insights to review the performance of the wastewater system under prevailing climate conditions and that might be expected under climate change (as below).
- **Projected climate change:** climate change scenarios and/or projections are typically updated during each IPCC assessment report cycle, at intervals of approximately 5-7 years. It may take several years between the release of the IPCC working group I report on the *Physical Basis of Climate Change* (IPCC, 2021) and the climate model outputs for that report becoming available in public data sets. Monitoring for changes in the science context for climate change is required to update any vulnerability, risk and/or impact assessments with new climate change projections and reviewing and, as necessary, adjusting planning, implementation and/or wastewater system asset management.

An example approach for monitoring climate hazard and boundary conditions that impact the wastewater system is included below.

Example wastewater network monitoring approach

Water utilities typically monitoring climate change conditions such as rainfall, flow, depth and velocity, and water quality within the sewer network to calibrate the projected climate change impacts relevant to their localised catchment and account for the uncertainty of climate change on the system.

All water utilities undertake varying extents of ambient and wastewater monitoring which can be incorporated, or ‘blended’, with the third-party data sources. Before it is blended, it is critical to validate the data against the third-party data to ensure they make sense together. If monitoring data is then combined with third-party data, it is equally critical that the process implemented to blend the data is documented in detail for future users to be able to delineate where the third-party data has been modified.

It may benefit water utilities to utilise the outputs of the monitoring plan to identify where additional monitoring would benefit their climate change risk management strategy.

Key steps to take in developing required monitoring are:

- Understand the existing available third-party information and its geographical relevance
- Identify what existing monitoring is available and where there are ‘data gaps’ that need to be addressed
- As well as filling the ‘data gaps’, ongoing monitoring can allow validation of the climate change projections, providing flexibility for water authorities to adapt as required. There are two key climate systems relevant to the sewer network; ambient and the sewer, discussed below.

Ambient monitoring

- Monitoring and assessment of climate change data, specifically the key climate change conditions such as rainfall, temperature, and sea level rise, will continue to be undertaken by government bodies. These will provide a general indication of the climate change trends, though more local information may be sought out to provide granularity to identify the specific impacts to local water utilities.

Sewer monitoring

- Water utilities are well placed to monitor sewer flow rates as it is a key BAU parameter. With the data already being recorded, there is opportunity to corroborate climate change projections by:
- Comparing flowrates during various storm events to the ‘design storm events’ used for asset design.
- Comparing storm event intensity and duration to the volume of ingress to sewer, to understand the relationship between the ambient rainfall and the wastewater network rainfall ingress

Wastewater network monitoring opportunities include:

- Monitoring the change in influent wastewater quality in STPs to identify changes over time that may be attributed to climate change are another source of BAU data, where the change in influent wastewater quality can be monitored to identify changes over time that may be attributed to climate change.
- Monitoring for the lead indicators of odour risk, such as dissolved sulphate and H_2S gas phase concentration, sewage temperatures relative to ambient temperatures (to understand their relationship) can assist in developing an understanding of odour risk. This can then allow proactive mitigation to be carried out, rather than relying on odour complaints to be reported. Monitoring the lead indicators is also integral to identifying corrosion risk within the wastewater network.

Monitoring sea level ingress into the sewer through electrical conductivity monitoring. This can be a key factor to projecting corrosion risks in the wastewater network and effluent quality risks from wastewater

6.2 Reviewing climate change obligations, objectives and priorities

Monitoring is required to gather information about the performance of the wastewater system in reaching climate-related obligations and objectives. This includes reviews to assess and improve the effectiveness of interventions and system performance. Such reviews would also support internal and any external climate risk disclosures.

Climate change vulnerability and risk assessments should be revised periodically to take account of:

- new climate change obligations or objectives,
- new climate change projection information,
- the system's performance under prevailing climate, and
- advancements in understanding of the causal links between climate and wastewater system performance.

These updated assessments may highlight new priorities that would then inform reviews of planning, implementation and asset management.

6.3 Evaluating the performance and effectiveness of adaptation plans

Monitoring and review should provide critical input into periodic adjustments to plans and the refinement of future interventions. Adjustment and refinement should be based on evaluation of the appropriateness, effectiveness, efficiency and impact of plans, and be supported by data and information from monitoring the climate context and the system's performance.

From a climate change perspective, the key aspects to consider are:

- What climate conditions have been experienced?
- How did the wastewater system experience those conditions and how did it perform? Monitoring of climate conditions and how they were experienced by the wastewater system would inform reviews of how the system performed under those conditions, with a focus on:
  - Climate events that disrupted the system in some way (e.g., drought resulting in tree root intrusion, leading to sewer blockages or dry weather spills)
  - Events that were potentially disruptive, but did not lead the system to operate outside its limits (heavy rainfall events that did not lead to spills)
  - System condition and/or performance in response to longer term trends (e.g., rate of sewer corrosion under warming temperature, flow rates in coastal sections of the sewer network in response to sea level rise).
- What modifications to plans and/or interventions are required to provide resilience under climate change? Reviews of system performance under experienced climate conditions, combined with (any) updated information on climate change or climate change impacts may lead to a reappraisal of plans, interventions used in response to climate change and/or refinement of on-going asset management.

6.4 Identifying triggers and decision points

Monitoring and review is critical for implementation of an adaptive plan by detecting triggers and decision points. These may relate to:

- Progress with initiatives to align KVR, which are necessary for the next step in an intervention pathway. Monitoring of progress with climate related and other KVR initiatives will signal that new interventions are now available for implementation when needed.
- Identification of system limits: monitoring and review of triggers and decision points is intended to enable timely decisions on the introduction of new interventions to prevent systems from reaching or exceeding their limits and hence not achieving performance objectives or breaching regulatory or other obligations. Some of system limits may be influenced by climate conditions. For example, operation of some existing wastewater infrastructure in coastal areas may be safe until mean sea

levels rise by 0.5 m. After reaching this level some kind of intervention (e.g., coastal defence, retreat inland) will have to have been implemented to enable safe operation within regulatory obligations and service objective limits. Trigger levels and decision points, based on sea level rise (<0.5m) will have been set in the adaptive plan to ensure interventions are implemented before system limits are reached.

7. References

Bureau of Meteorology & CSIRO . (2018). *State of the Climate 2018.*

Clarke, J., Thatcher, M., Hermanman, V., Heady, C., Round, V., Rafter, T., . . . Wilson, L. (2019). *Victorian Climate Projections 2019 Technical Report.* Melbourne: CSIRO.

CSIRO and Bureau of Meteorology. (2015). *Climate Change in Australia Information for Australia's Natural Resource Management Regions: Technical Report.* Australia: CSIRO and Bureau of Meteorology.

DELWP. (2017). *Planning Permit Applications Bushfire Management Overlay - Technical Guide.*

DELWP. (2018). *Pilot Water Sector Climate Change Adaptation Action Plan.* Retrieved from Water Victoria: https://www.water.vic.gov.au/__data/assets/pdf_file/0019/410851/WSAAP-Web-version-FINAL_v2.pdf

DELWP. (2019). *Victoria's Climate Science Report.* Australia: DELWP.

DELWP. (2020). *Guidelines for Assessing the Impact of Climate Change on Water Availability in Victoria (Final).* Department of Environment, Land, Water and Planning.

DELWP. (2021, March). *Guidelines for the development of urban water strategies.* Retrieved from Victoria State Government, Environment, Land Water Planning: https://www.water.vic.gov.au/__data/assets/pdf_file/0025/519802/Guidelines-for-the-development-of-urban-water-strategies_Final.pdf

DELWP. (2021). *Victoria's water in a changing climate. Insights from the Victorian Water and Climate Initiative.* DELWP.

DELWP. (2022). *Water Cycle Adaptation Action Plan 2022-2026.* Department for Environment Land Water Planning.

Denson, E., Wasko, C., & Peel, M. C. (2021). Decreases in relative humidity across Australia. *Environmental Research Letters*.

Donat, M. G., Yang, A. H., Durre, I., Vose, R., Dunn, R. J., Willett, K. M., . . . Klein Tank, A. M. (2015). Updated analyses of temperature and precipitation extreme indices since the beginning of the twentieth century: The HadEX2 dataset. *Journal of Geophysical Research: Atmoshpheres*, 2098-2118.

EPA. (1991). *Guidelines for Wastewater Irrigation, Publication 168.*

EPA. (2004). *943: Guidelines for environmental management: biosolids land application.*

EPA. (2018). *State Environment Protection Policy (Waters) Monitoring, Evaluation and Reporting Framework.* EPA. Retrieved from DELWP: https://www.water.vic.gov.au/__data/assets/pdf_file/0014/400721/MER-Framework.pdf

EPA. (2020). *1707.1: Sewerage Management Guidelines .*

EPA. (2021). *1910.2: Victorian guideline for water recycling.*

EPA. (2022). *Guideline for Assessing and Minimising Air Pollution.*

Grose, M., Abbs, D., Bhend, J., Church, J., Ekstrom, M., Kirono, D., . . . Whetton, P. (2015). *Southern Slopes Cluster Report, Climate Change in Australia Projections for Australia's Natural Resource Management Regions: Cluster Reports.* Australia: CSIRO and Bureau of Meteorology.

Guerreiro, S., Fowler, H., Barbero, R., & Westra, S. (2018). Detection of continental-scale intensification of hourly rainfall extremes. *Nature Climate Change, 8*.

HARC. (2019). *Representing climate change projections in rainfall, evaporation and sea level inputs to hydraulic models of Melbourne's sewer network. .* Melbourne Water.

Hope, P., Timbal, B., Hendon, H., Ekstrom, M., & Potter, N. (2017). *A synthesis of findings from the Victorian Climate Initiative (VicCI).* Australia: Bureau of Meteorology.

Hutley, N., & Hartford Davis, S. (2019). *"Climate Change and Directors' Duties" Supplementary Memorandum of Opinion.* Centre for Policy Development.

Hyghes, J., Cowper-Heays, K., Olesson, E., Bell, R., & Stroombergen, A. (2021). Impacts and implications of climate change on wastewater systems: A New Zealand perspective. *Climate Risk Management, 31*.

IPCC. (2013). *Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Intergovernmental Panel on Climate Change.

IPCC. (2021). *Climate Change 2021: The Physical Science Basis Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Retrieved from IPCC: https://www.ipcc.ch/report/ar6/wg1/

IPCC. (2022). *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* . Retrieved from IPCC: https://www.ipcc.ch/report/ar6/wg2/

Jacobs, [. C. (2011). *Assessment of Potential Impacts on the Sewerage System by Advanced Water Efficiency Measures: Target Research and Development Funding Stream, report for Smart Water Fund.* Victorian Government.

Marlow, D., Boulaire, F., & Beale, D. J. (2010). Sewer Performance Reporting: Factors That Influence Blockages. *Journal if Infrastructure Systems*, 42-51.

McInnes, K. M. (2008). *Effect of Climate Change on Extreme Sea Levels in the Western Port Region, Impacts of Climate Change on Human Settlements in the Western Port Region: An Integrated Assessment.* CSIRO Marine and Atmosphere.

McInnes, K. M. (2009). *A Modelling Approach for Estimating the Frequency of Sea Level Extremes and the Impact of Climate Change in Southeast Australia.* Retrieved from Natural Hazards. 51. 115-137. : https://doi.org/10.1007/s11069-009-9383-2

Meteorology, C. a. (2015). *Climate change in Australia, projections for Australia's Natural Resource Management Regions, Technical Report.* CSIRO and Bureau of Meteorology, Australia.

New Zealand Government, Ministry for the Environment. (2017). *Preparing for coastal change, A summary of coastal hazards and climage change guidance for local government.* Wellington: Ministry for the Environment.

Petzold, B., Roggendorf, M., Rowshankish, K., & Sporleder, C. (2020, June). *Designing data governance that delivers value.* Retrieved from McKinsey Digital - Our Insights: https://www.mckinsey.com/business-functions/mckinsey-digital/our-insights/designing-data-governance-that-delivers-value

Potter, N. J., Chiew, F. H., Zheng, H., Eksirom, M., & Zhang, L. (2016). *Hydroclimate projections for Victoria at 2040 and 2065.* Australia: CSIRO.

Ren, Z. J., & Pagilla, K. (2022). *Pathways to Water Sector Decarbonization, Carbon Capture and Utilization.* IWA Publishing.

Standards Australia. (2013). *5334-2013: The Australian Standard for Climate change adaptation for settlements and infrastructure.* Standards Australia.

Standards Australia. (2018). *ISO31000:2018 Risk management guidelines.* Standards Australia.

Steffan, W., Vertessy, R., Dean, A., Hughes, L., Bambrick, H., Gergis, J., & Rice, M. (2018). *Deluge and Drought: Australian's Water Security in Changing Climate.* Climate Council of Australia.

Stewart, M. G., Wang, X., & Nguyen, M. N. (2010). *Climate Change Impact and Risks of Concrete Infrastructure Deterioration.* CSIRO.

TCFD. (2017). *The Use of Scenario Analysis in Disclosure of Climate-Related Risks and Opportunities.* Task Force on Climate Related Financial Disclosure.

The State of Queensland (Department of Environment and Science). (2018, May 22). *MEDLI - Software for effluent reuse schemes*. Retrieved from Queensland Government: Science - Department of Environment and Science: https://science.des.qld.gov.au/government/science-division/medli

Timbal, B., Abbs, D., Bhend, J., Chiew, F., Church, J., Ekstrom, M., . . . Wehtton, P. (2015). *Murray Basin Cluster Report, Climate Change in Australia Projections for Australia's Natural Resource Management Regions: Cluster Reports.* Australia: CSIRO and Bureau of Meteorology.

WSAA. (2012). *Climate Change Adaptation and the Australian Urban Water Industry.* WSAA.

WSAA. (2016). Leading Practices Compendium. *Asset Management Customer Value (AMCV).* Melbourne: WSAA.

8. Further reading on climate change

More detailed information on the key drivers of Victoria's climate variability and on observed and projected future changes in Victoria's climate may be obtained from several key sources, including:

- Victoria's water in a changing climate. Insights from the Victorian Water and Climate Initiative (DELWP, 2021)
- Victorian Climate Projections 2019 (VCP19). Technical Report (Clarke, et al., 2019)
- Guidelines for Assessing the Impact of Climate Change on Water Availability (DELWP, 2020)
- Hydroclimate projections for Victoria at 2040 and 2065 (Potter, Chiew, Zheng, Eksirom, & Zhang, 2016)
- A synthesis of findings from the Victorian Climate Initiate (VicCI) (Hope, Timbal, Hendon, Ekstrom, & Potter, 2017)
- Victoria's Climate Science Report 2019 (DELWP, 2019)
- Climate change in Australia (CCIA) Technical Report (CSIRO and Bureau of Meteorology, 2015) and its cluster reports applicable to Victoria: Murray Basin (Timbal, et al., 2015) and Southern Slopes (Grose, et al., 2015)

Appendices

A.1 Climate change potential impacts on the wastewater system

A.1.1 Summary of the potential impacts of climate conditions on wastewater infrastructure and water and biosolids reuse

<table>
<tr><th rowspan="2">Climate hazard condition</th><th rowspan="2">Potential impacts</th><th colspan="5">Consequences</th></tr>
<tr><th>Sewer Network</th><th>Pump Stations</th><th>Treatment Plants</th><th>Water Recycling</th><th>Biosolids</th></tr>
<tr><td rowspan="5">Larger heavy rainfall events, stormwater & riverine flooding</td><td rowspan="5">• Increased peak sewer flow rates due to inflow and infiltration
• Flooding of sewer network, pump stations, treatment infrastructure & recycled water and biosolid storages</td><td colspan="2">Sewage spills to surface environment</td><td>Disruption to treatment processes</td><td></td><td></td></tr>
<tr><td colspan="3">Infrastructure – pipes, pumps, etc undersized for flows</td><td></td><td></td></tr>
<tr><td colspan="5">Damage to assets affected by flooding. Disruption to operations</td></tr>
<tr><td></td><td></td><td colspan="3">Uncontrolled release of treated water &/or waste to environment</td></tr>
<tr><td colspan="5">Community, regulatory &/or environmental impact from contamination</td></tr>
<tr><td rowspan="6">Increased average & extreme temperatures, heatwaves</td><td rowspan="6">• Increased odour generation & emissions
• Accelerated corrosion of sewer pipes
• Mechanical failure of infrastructure. Heat-related failure of electrical &/or electronic infrastructure
• Increased/peaks in water and recycled water use/demand by customers
• Altered rates of biological treatment processes
• Increased power requirements/usage to control temperature of mechanical and electrical equipment
• Increased incidence of spontaneous combustion of biosolids stockpiles
• Temporary reduction/loss of grid power supply due to excessive demand & associated load shedding</td><td colspan="3">Community & regulatory impact from odour generation</td><td>Increased demand for recycled water</td><td>Increased rate of sludge drying</td></tr>
<tr><td colspan="3">Failure of corrodible sewer infrastructure</td><td></td><td></td></tr>
<tr><td colspan="5">Asset mechanical/structural &/or electrical failure due to excessive heat. Service disruption</td></tr>
<tr><td colspan="3">Sewage more highly concentrated – alteration of sewer corrosion, odour & treatment process</td><td></td><td>Dust generation from biosolid stockpile</td></tr>
<tr><td colspan="3">Service disruption due to grid power supply failures</td><td></td><td>Spontaneous combustion & fire</td></tr>
<tr><td></td><td></td><td>Altered treatment process efficiency</td><td></td><td></td></tr>
<tr><td rowspan="4">Drier conditions (reduced rainfall, greater evaporation), more severe droughts</td><td rowspan="4">• Dry soils lead tree roots to seek water
• Enhance shrink-swell of soils under alternate dry/wet conditions
• Low flows in waterways to which treated water/spills discharged
• Reduced sewer flow and change in sewage concentrations
• Increased/peaks in water and recycled water use/demand by customers
• Groundwater levels fall
• Reduced soil corrosivity</td><td colspan="2">Sewer damage due to soil movement, soil corrosivity and tree root penetration</td><td></td><td>Increased demand for recycled water</td><td>Increased rate of sludge drying</td></tr>
<tr><td colspan="2">Dry weather sewer blockages & spills. Service disruption</td><td colspan="2">Inability to discharge spills or recycled water to waterway due to low flow in receiving environment</td><td>Dust generation from biosolid stockpile</td></tr>
<tr><td colspan="3">Sewage more highly concentrated – alteration of sewer corrosion, odour & treatment process</td><td>Increased capacity to use/evap recycled water</td><td></td></tr>
<tr><td colspan="4">Community, regulatory & environmental impact from odour generation, spills and water discharge</td><td></td></tr>
<tr><td rowspan="4">Sea level rise, coastal flooding & erosion</td><td rowspan="4">• Elevated groundwater levels and groundwater ingress to sewers
• Sea water inflows to sewers
• Change in sewer flows and sewage chemistry
• Flooding of infrastructure in coastal locations
• Saltwater intrusion to coastal treatment assets
• Coastal retreat/erosion near wastewater assets
• Increased soil corrosivity</td><td></td><td></td><td colspan="2">Disruption to treatment processes & reuse due changed flow & salinity</td><td>Shallow groundwater slows sludge drying</td></tr>
<tr><td colspan="3">Infrastructure – pipes, pumps, etc undersized for flows</td><td colspan="2">Shallow groundwater makes land unsuitable for recycled water use, biosolids storage/use</td></tr>
<tr><td colspan="4">Damage to assets affected by flooding, shallow groundwater &/or coastal erosion</td><td></td></tr>
<tr><td colspan="4">Accelerated corrosion of materials due to salinity & moisture</td><td></td></tr>
<tr><td rowspan="3">More severe bushfire weather</td><td rowspan="3">• Damage to assets
• Ash and particulate contamination in stormwater entering sewer network
• Interruption to power supply/loss of power supply infrastructure</td><td></td><td colspan="3">Damage to assets, service disruption</td><td></td></tr>
<tr><td colspan="2">Sewer spills due to failure of pumps</td><td>Altered treatment process with ash</td><td></td><td></td></tr>
<tr><td colspan="4">Community, regulatory & environmental impact from spills</td><td></td></tr>
<tr><td rowspan="2">Reduction in ambient air humidity</td><td rowspan="2">• Altered sewer dry wall lengths
• Reduced corrosion rate and odour generation
• Increased evaporation rates & demand for water</td><td colspan="2">Changes to corrosion potential</td><td></td><td>Increased recycled water use rates</td><td>Increased rate of sludge drying</td></tr>
<tr><td colspan="2">Changes to odour generation</td><td></td><td></td><td>Dust generation from biosolid stockpile</td></tr>
<tr><td>Elevated CO2</td><td>• Accelerated concrete corrosion/carbonation</td><td colspan="3">Reduced operating life of long-lived concrete structures</td><td></td><td></td></tr>
<tr><td rowspan="2">Changes in average & extreme winds</td><td rowspan="2">• Reduced average wind speed
• Increased extreme wind speed</td><td colspan="2">Reduction in odour dispersion</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td>Wind damage to structures</td><td></td><td></td></tr>
</table>

A.1.2 Sewage Transfer Network

The sewage transfer network primarily consists of the network of underground pipes, the sewer access structures and emergency relief discharge locations. Some operate using gravity to transfer the sewage, and some are pumped. Gravity-fed and pumped operate systems have different risk profiles when considering climate change impacts. A broad range of climate parameters needs to be considered in the context of climate change, with key potential consequences including increased frequency and magnitude of spills (ability to manage sewage flows) and the increased likelihood of asset failure due to corrosion. A summary of potential impacts is listed in Table 20.

Table 20: Potential impacts of climate change on wastewater transfer networks

Potential key impacts on sewer transfer network	Potential impacts of climate hazard conditions
• *Increased frequency and magnitude of spills due to exceeding sewer network capacity* • *Accelerated corrosion assets* • *Increased likelihood of failure of assets as a result of the above impacts, as well as tree root ingress and bushfire* • *Increased odour generation*	**Rainfall (increased intensity of extreme rainfall events):** • Increased frequency and magnitude of spills and flooding due to larger peak flows. • Increased risk of structural failure of assets. • Increased risk of risk undersized transfer pipework. • Greater turbulence at locations throughout network, resulting in increase in H_2S release rate to sewer gas space and increased odour and corrosion risk. • More frequent pipe full surcharging could lead to erosion of backfill surrounding pipes through degraded rubber joints (EW pipes) or cracks/holes (all pipes) and create voids that can lead to collapse.
	Temperature (increased average and peak temperatures): • Increase in average sewage temperatures, resulting in increased sulphide generation rate in network, increased release of H_2S to sewer air space. Increase to network O&C and potential asset failure risk. [Reference: SCORe odour and corrosion research project undertaken by University of Queensland for the Australian water industry - and its outcomes and relevant empirical formulae.] • Higher sewer gas space temperatures resulting in increased corrosion rates in network (corrosion rate proportional to gas phase temperature). • Increase in sewer gas buoyancy resulting in increased rate of foul air outgassing at network vents and sewerage network openings (e.g., leaking manholes). • Increased network odour impact risk.
	Dry conditions: • Increased risk of asset failure due to pipe cracking (caused by cyclic wetting/drying) and tree root ingress (from prolonged drought periods). • More concentrated average sewage characteristics due to lower water use and reduced rainfall/groundwater infiltration • Increased risk of dry weather spills to waterways that don’t contain running surface water • Longer sewage residence times in network and subsequent higher sulphide generation rate. May also impact sewer gas composition (e.g., H_2S, mercaptans and other reduced sulphide components) due to changes in extent of anaerobic conditions. • Potential for increased build-up of debris resulting in increased local sulphide generation.
	Humidity (reduced ambient air humidity due to lower air moisture content, increased sewer humidity due to rising average temperatures): • Increased risk of odour emissions due to increased sewer humidity being more suitable for odour generation.

	• Higher ambient humidity may reduce efficiency of forced ventilation systems which may increase odour and corrosion risk. • Higher sewer gas space humidity (i.e., kg moisture per kg dry air) may occur due to increased sewer gas temperatures, resulting in increased corrosion rates. Corrosion rate is proportional to gas phase relative humidity, with corrosion rate increasing significantly for relative humidity increases above 85%. • Higher ambient relative humidity may cause a lower driving force for naturally ventilated sewer systems, less dilution of sewer gas space, resulting in higher H_2S/odour levels in sewers. • Greater relative humidity variation between seasons may speed up corrosion of corrodible assets. • Overall increase in O&C risks for networks with natural ventilation.
	Sea level rise/flooding: • Changing seawater inundation in coastal areas may cause increased seawater ingress to sewer. This requires higher design flow requirements • Accelerated corrosion rates of corrodible assets due to increased salinity concentration in the sewer and contact of seawater with aboveground assets • Increased rate of seawater ingress to network may result in higher sulphide generation rates, specifically in pressure mains. • Increased risk of asset damage/loss from both gradual and / or storm surge-based inundation. • Increased risk of sewage spills causing asset damage/destruction.
	Bushfire (increased frequency of bushfire-prone ambient conditions): • Increased risk of aboveground asset failure due to bushfires • Increased power outage frequency for key monitoring assets, transfer pumping station and pumped ERS and level actuated penstock due to bushfire impacts to the broader power network
	Wind • Changes in wind speed, direction and atmospheric stability may impact atmospheric dispersion conditions and associated impacts of odour plumes (in the air and at ground level). Low risk of material impact.

A.1.3 Sewage Pumping Stations and Network Monitoring sites

Sewage pumping stations and network monitoring sites are considered together as they are both part of the sewage transfer network but are the primary locations of mechanical and electrical equipment. They have different potential impacts from climate change than the pipe network. The assets are more directly impacted by changes to the ambient conditions than the underground assets. A summary of potential impacts is listed in Table 21.

Table 21: Potential key impacts on sewage pumping stations

Potential key impacts on sewage pumping stations	Potential impacts of climate hazard conditions
• *Increased likelihood of undersized assets (pumps, wet well)*	**Rainfall (increased intensity of extreme rainfall events):** • Increased risk of mechanical and electrical asset failure. • Increased frequency and magnitude of spills and flooding due to larger peak flows increasing risk of undersized assets.

Potential key impacts on sewage pumping stations	**Potential impacts of climate hazard conditions**
• *Increased odour and corrosion risk* • *Failure of assets*	**Temperature (increased average and peak temperatures):** • Accelerated corrosion of assets • Increased odour emissions risk • Increased risk of asset failure for mechanical and electrical, instrumentation and control assets
	Dry conditions: • Increased risk of aboveground pipe cracking due to cyclic wetting/drying of pipes and exposure to extreme temperatures • Longer detention times of sewage in wet wells due to lower water use and increased corrosion and odour risk
	Humidity (reduced ambient air humidity due to lower air moisture content, increased sewer humidity due to rising average temperatures): • Refer to humidity impacts of the wastewater network.
	Sea level rise/flooding: • Increased risk of undersized assets due to increased seawater ingress to sewer • Increased rate of seawater ingress to network via infiltration for coastal catchments resulting in higher sulphide generation rates, specifically in pressure mains. • Increased risk of asset damage/loss from both gradual and / or storm surge-based inundation. • Increased risk of pump stations being within new flood zones.
	Bushfire (increased frequency of bushfire-prone ambient conditions): • Increased risk of asset failure due to bushfires. • Increased power outage frequency due to bushfire impacts to the broader power network.
	Wind • Refer to wind impacts of the wastewater network.

A.1.4 Wastewater Treatment Plants

Wastewater treatment plants have additional complexity relative to the other network assets due to the biological treatment process that is typically designed to operate with a certain operating band. Sewage characteristics can be affected by various climate parameters, and the sewage and infrastructure are typically exposed to ambient conditions, further exacerbating the complexity of designing and operating treatment plans for climate change impacts. A summary of potential impacts is listed in Table 22.

Table 22: Potential key impact on treatment plants

Potential key impact on treatment plants	Potential impacts of climate hazard conditions
• *Increased peak flows and process disruptions* • *Changes to sewage quality characteristics* • *Failure of assets due to accelerated corrosion of corrodible assets*	**Rainfall (increased intensity of extreme rainfall events):** • Increased risk of flooding of treatment plant sites. • Increased peak flows may cause process disruptions and inadequate treatment, spills, and require additional bypass infrastructure to either store or discharge the excess wet weather flows. This may also result in exceedance of licences conditions. • Increased treatment plant capacity requirements and power usage for pumping of flows. • Increased sewage spills following severe storm events due to increased power outages. • Increased risk of loss of treatment capacity and/or inadequate treatment due to severe storm events (increased power outages).
	Temperature (increased average and peak temperatures): • Changes to operating conditions of the treatment processes. • Increase in H_2S. Overall increase to odour and corrosion risk particularly at process units most susceptible to H_2S gas release, i.e., at inlet works and primary sedimentation tanks. • Increased risk of electrical/mechanical asset failure (particularly for aboveground assets directly influenced by ambient temperature). • Increased need for air-conditioned facilities increasing site power requirements. • Increased frequency of power failure due to high power demand on the broader power network. • Higher biological activity rates due to warmer average temperatures. Whilst unlikely to result in significant changes to plant capacity, should be allowed for in the climate change modelled scenarios. • Decreased air/oxygen transfer rates into wastewater potentially increasing blower capacity.
	Dry conditions: • Longer residence time in network and more concentrated sewage characteristics due to lower water use and reduced rainfall/groundwater infiltration. • Increased design load rates and odour and corrosion risk particularly at the plant inlet. A key parameter for some treatment facilities is the COD:TKN ratio. • Increased risk of corrosion due to higher strength wastewater during low flow / drought conditions. • Increased risk to meeting effluent quality requirements during drought periods due to more highly concentrated influent conditions (more concentrated average sewage quality) • If sewage transport times increase, sedimentation and fermentation could occur in the network, which would be beneficial to biological phosphorus removal processes, but has a negative effect on primary treatment.
	Humidity (reduced ambient air humidity due to lower air moisture content, increased sewer humidity due to rising average temperatures): • Increased corrosion and odour risk

Potential key impact on treatment plants	Potential impacts of climate hazard conditions
	Sea level rise/flooding: • Increased risk of loss of nitrification (ammonia treatment) if short-term peaks in influent seawater are observed in the influent (increased salinity) due to sea water ingression. • Long term design load changes due to increase in total dissolved solids (TDS) concentration in sewer from sea water. • Longer term high influent salinity may cause corrosion of corrodible assets. • Increased risk of asset damage/loss from both gradual and / or storm surge-based inundation. • Increased risk of supply chain interruption for critical chemicals.
	Bushfire (increased frequency of bushfire-prone ambient conditions): • Increased frequency of short-term concentrated sewage (nutrients, contaminants) due to bushfire ash and stormwater runoff ingress to sewer. • Increased power outage frequency due to bushfire impacts to the broader power network. • Impact on assets due to fire damage or loss of incoming power supply. • Increased risk of asset damage / loss. • Increased risk of supply chain interruption for critical chemicals.
	Wind • Changes in wind speed, direction and atmospheric stability may impact atmospheric dispersion conditions and associated impacts of odour plumes (in the air and at ground level). Low risk of material impact.

A.1.5 Recycled Water Treatment

Recycled water production and distribution typically is the end result of wastewater treatment facilities. The climate change impacts on recycled water, as considered in Table 23, are primarily on the demand for recycled water to supplement potable water use.

Table 23: Potential key impacts on recycled water treatment

Potential key impact on recycled water	Potential impact of climate hazard conditions
• *Increased recycled water demand* • *Decreased reliability of recycled water supply*	**Rainfall (increased intensity of extreme rainfall events):** • Increased frequency of short to medium term treatment plant process disruptions. This may reduce reliability of recycled water production. • Increased winter storage requirements where recycled water is stored for summer demands. • Decreased requirement for recycled water by the recycled water users and therefore risk of non-compliance where the plant relies on water recycling for effluent disposal. • Risk of inundation of low-lying effluent discharge outlets.
	Temperature (increased average and peak temperatures): • Increased water use by consumers during periods of high temperature. • Risk of inadequate treatment due to loss of mechanical/electrical equipment during extreme heat days.

Potential key impact on recycled water	Potential impact of climate hazard conditions
	Dry conditions: • In drought conditions the demand for recycled water may increase, putting pressure on recycled water supply. • Risk to recycled water storages during prolonged drought conditions (e.g., increase water loss from evaporation and potential for clay liner cracking). • Diverting effluent from discharge to reuse may have a positive (e.g., ceasing nutrient and contaminant emissions into waterways) or negative (e.g., removing a source of water during drought) effect on environments where treated effluent is usually discharged. • Risk of tighter effluent quality requirements being introduced to protect the environment during periods of drought (due to reduced dilution in the receiving environment).
	Humidity (reduced ambient air humidity due to lower air moisture content, increased sewer humidity due to rising average temperatures): • No material impacts
	Sea level rise / flooding: • Risk of production of poor-quality recycled water / loss of recycled water customers due to high salinity from seawater ingression. • Increased in influent water quality variability and TDS from seawater intrusion requiring adjustments to or refinement of process treatment technology selection, such as the requirement for reverse osmosis treatment for recycled water production. • Risk of sea level intrusion / flooding in low lying areas, potentially impacting recycled water storage and irrigation areas for sewage treatment plants. • Risk of spills due to reduced effluent discharge capacity (gravity or pumped) due to flooding or sea level rise (gradual and/or storm surge-based inundation of coastal treatment plants). • Increased risk of asset damage/loss from both gradual and / or storm surge-based inundation. • Increased risk of supply chain interruption for critical chemicals.
	Bushfire (increased frequency of bushfire-prone ambient conditions): • Increased risk of water quality contamination due to bushfire ash entering treated water storages. • Increased risk of inadequate recycled water demand due to damage/destruction of land irrigation infrastructure, i.e., loss of tree crops • Increased risk of asset damage / loss. • Increased risk of supply chain interruption for critical chemicals.

A.1.6 Biosolids Management

A sub-set of wastewater treatment plants, biosolids management is a key component that is influenced by potential climate change impacts.

Table 24: Potential key impacts on biosolids management

Potential key impact on biosolids management	Potential impacts of climate hazard conditions
• *Changes to receiving environment make it unsuitable for biosolids disposal* • *Variable sludge drying rates*	**Rainfall (increased intensity of extreme rainfall events):** • A lower net evapotranspiration rate and reduced biosolids drying rate resulting in an increase in required drying area where sludge drying pans are used for solids drying. • Risk of variability in demand for biosolids product for agriculture over the climate period, with greater demand in dryer years and reduced demand in wetter years.
	Temperature (increased average and peak temperatures) / dry conditions: • Improved sludge drying rates for solar dryers, though also conducive to increase odour risk due to hot, dry weather conditions. • Increased fire risk (from self-heating) at biosolids handling / treatment sites. • Increased risk of inadequate treatment due to loss of mechanical/electrical equipment during extreme heat days. • For land-based sludge drying, risk to sludge drying pan assets during prolonged drought conditions (e.g., potential for clay liner cracking).
	Humidity (reduced ambient air humidity due to lower air moisture content, increased sewer humidity due to rising average temperatures): • Reduced ambient air humidity may improve sludge drying rates.
	Sea level rise: • Low-lying coastal areas may be less suitable for biosolids land application due to sea level rise. • Increased risk of asset damage/loss from both gradual and / or storm surge-based inundation.
	Bushfire (increased frequency of bushfire-prone ambient conditions): • Increased risk of asset damage / loss.
	Wind • Changes in wind speed, direction and atmospheric stability may impact atmospheric dispersion conditions and associated impacts of odour plumes (in the air and at ground level). Low risk of material impact.

A.1.7 Asset Integrity

Examples of potential impacts of climate hazard conditions to the asset integrity in addition to the impacts list above is included below.

Table 25: Potential key impacts on asset integrity

Asset Type	Potential impact of climate hazard conditions
Mild steel cement lined pipelines	• External corrosion due to increased soil corrosivity and damaged, delaminating or missing coatings. • Internal corrosion. • Joint movement (degradation of joint material).
Cast iron cement lined pipelines	• External corrosion due to increased soil corrosivity and damaged, delaminating or missing coatings. • Joint movement (degradation of joint material). • Tuberculation where internal lining has failed or missing (older unlined pipes).

Asset Type	Potential impact of climate hazard conditions
Ductile iron cement lined pipelines	• External corrosion due to increased soil corrosivity and damaged, delaminating or missing coatings / sleeve. • Joint movement (degradation of joint material).
Plastic (PVC, PE and Glass Reinforced Plastic)	• Ultra-violet (UV) radiation and heat intensity (above ground installations). • External loading damage e.g., point loading from rocks/stones in bedding material (below ground installation) – voids created in bedding material.
AC pipelines	• Internal / eternal corrosion. • Fracture pipework due to ground movement
Lagoons, retaining basins, levee banks	• Changing soil moisture conditions resulting in damage to clay core or surface. • Flexible covers – reduced asset life due to higher UV – structural loading of covers associated with water loading / higher intensity rainfall events. • Increased erosion when subject to higher flows resulting increase rainfall intensity (e.g., structures adjacent to drains / waterways. • Foreshore flooding / foreshore erosion for to storms (e.g., structures located on bays and ocean shorelines.
Concrete structures	• External soil corrosion / corrosive environments (including increased corrosion rates due to higher ambient CO_2 concentrations). • Internal corrosion. • More frequent surcharging in manholes and structures due to higher intensity rainfall leading to increased internal pressure and structural failure (fatigue failure). • Inundation and undermining of structures.

A.2 How Victoria's climate may change

This section provides a summary of how the key wastewater system climate hazards may change in response to projected climate change. More detailed information on the key drivers of Victoria's climate variability and on observed and projected future changes in Victoria's climate may be obtained from several key sources listed in Section 0.

Summaries of climate change projections are provided for each region of Victoria in the climate change adaptation strategies (https://www.climatechange.vic.gov.au/supporting-local-action-on-climate-change) that have been prepared for the six main regions of Victoria.

A.2.1 Heavy rainfall

Warming of the atmosphere globally has contributed to increases in average and heavy rainfall, trends which are projected to continue with climate change. Globally, average annual rainfall is projected to rise by about 3% per °C of warming and heavy rainfall is projected to increase by 7% per °C of warming (IPCC, 2021).

Ocean and atmospheric circulation patterns mean that these trends will not be expressed consistently across the globe. In southern Australia, average annual rainfall is projected to decline with climate change rather than increase. While annual rainfall and rainfall in some seasons is projected to decline in Victoria, extreme daily or sub-daily rainfall are projected to increase (Clarke, et al., 2019).

Projections of changes in heavy rainfall published on the Australian Rainfall and Run-off (AR&R) Data Hub (https://data.arr-software.org/) are based on such events increasing by 5% per °C of warming (Ball *et al*., 2019), which equates to changes of 7.6% and 16.3% for RCPs 4.5 and 8.5 in 2090, respectively in southern Victoria and 9.2% and 20.2% in 2090, respectively, in northern Victoria.

The nature of projected changes in heavy rainfall with climate change remains uncertain due to the high degree of variability (Bureau of Meteorology & CSIRO, 2018) and limits on the capacity of global climate models to represent the processes involved in heavy rainfall events. The rate of increase in rainfall extremes based on thermodynamic expectations, referred to as Clausius–Clapeyron (CC) scaling, is estimated to be approximately 6.5% per 1.0 °C warming (Bureau of Meteorology & CSIRO, 2018); (Guerreiro, Fowler, Barbero, & Westra, 2018). This is supported by climate models and some observational data (Bureau of Meteorology & CSIRO, 2018); (Guerreiro, Fowler, Barbero, & Westra, 2018). Donat *et al*. (2013) found that increases in extreme precipitation followed CC scaling to durations of up to 5 days. Guerreiro *et al.* (2018) found that some sub-daily rainfall extremes have increase by twice the rate, or more in some cases, than that expected from CC scaling.

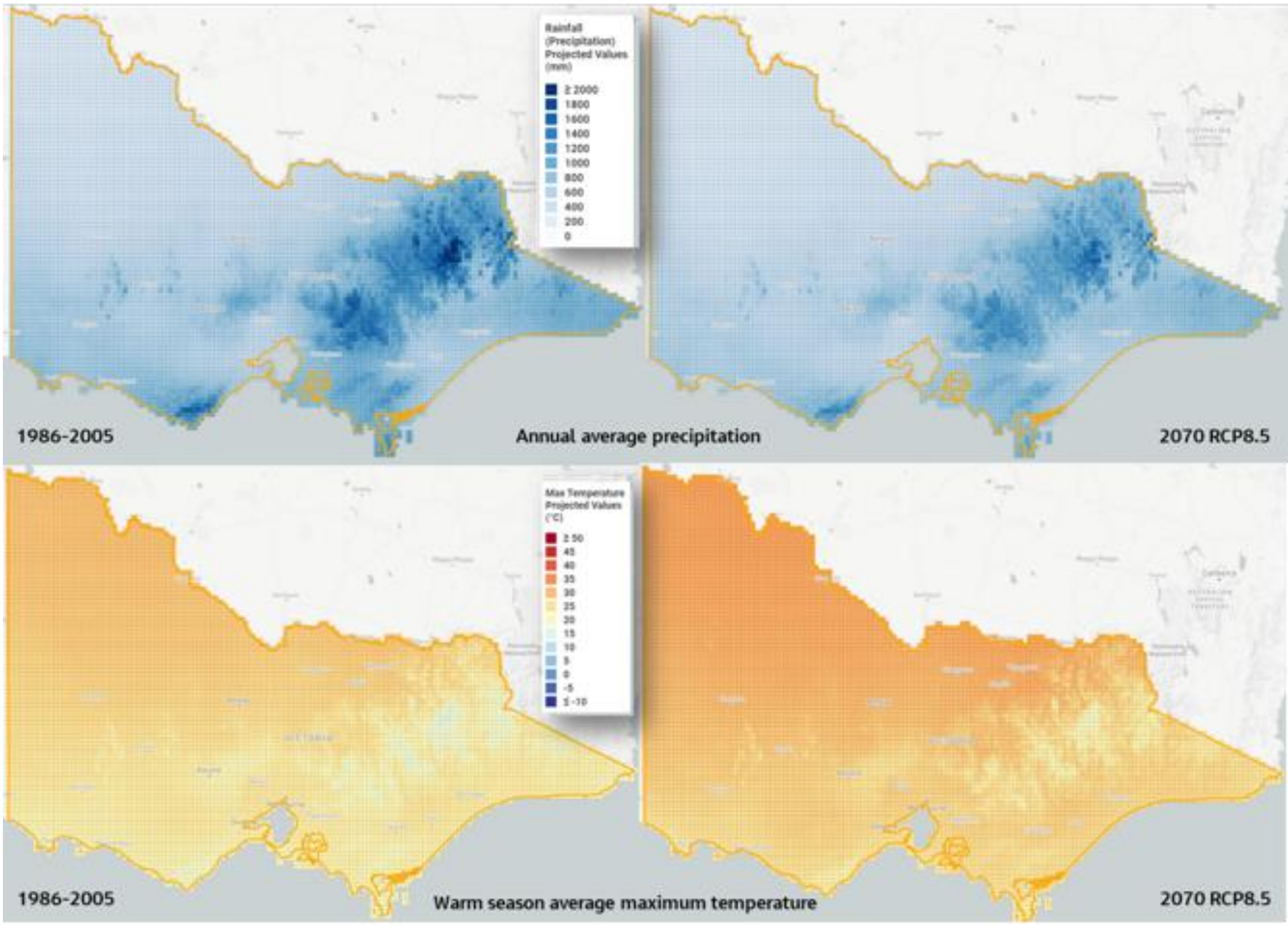


Figure 28: Historical (1986-2005) and projected 2070 RCP8.5 annual average precipitation and warm season average maximum temperature for Victoria. Source: Victoria's Future Climate Tool; https://vicfutureclimatetool.indraweb.io/project.

A.2.2 Temperature

Victoria's climate has warmed by just over 1°C since official records began in 1910 (BoM, 2019). There have been many more warm years than cool years since the 1960s. Compared to the average conditions observed during the reference period of 1961–1990, the last year with below-average temperature was 1996 (Clarke *et al.*, 2019).

Future climate change is projected to increase average, maximum and minimum daily, seasonal and yearly temperatures across Victoria (Figure 28:). The incidence of hot days and heatwaves is projected to increase, and the incidence of frosts and freezing days is projected to decline. The amount of change is projected to increase over the course of this century and be greater under higher emissions scenarios. Warming is projected to be greater for maximum than minimum temperatures and in inland areas of the state than along the coast. Changes in temperature are projected to be greater in spring and summer than at other times of year (Clarke *et al.*, 2019).

A.2.3 Drier climate

Victoria's rainfall patterns are influenced by large scale and interacting climate phenomena operating in the Indian, Pacific, and Southern Oceans (DELWP, 2019). Climate change has already disrupted some of these and is projected to significantly alter some major drivers of rainfall for the state.

Annual rainfall throughout Victoria is projected to decline during the course of this century (Figure 28:), with that decline most pronounced under higher emissions scenarios and in the latter part of this century. To about mid-century, rainfall patterns are projected to be dominated by natural variability and there is a reduced drying signal in some parts of the state (particularly Gippsland), where the direction of change in future rainfall is not as clear. Towards the end of the century, annual rainfall may decline by over 25% under a high emissions scenario in parts of northern and western Victoria (Steffan, et al., 2018).

Seasonal rainfall patterns are also projected to change, with the percentage change in rainfall during summer being less than that projected for other times of year, increasing the severity and frequency of drought. (Steffan, et al., 2018).

While projections of change in average rainfall are more certain than those for heavy rainfall, they are typically less certain than those for temperature.

Drying due to changes to Victoria's rainfall is projected to be compounded by increased rates of pan or potential evaporation (Clarke *et al.*, 2019; DELWP, 2021). Annual pan evaporation is projected to increase by about 10-20% by 2050 and as much as 18-35% by 2090 (for RCPs 4.5/8.5), with the percentage and absolute change being greater in spring and summer than at other times of year.

The combination of reduced rainfall and increased evaporation is projected to lead to reductions in annual run-off and groundwater recharge[3] (DELWP, 2016; 2020).). Projected changes in annual average runoff in the south-west of Victoria show a strong drying trend, with 2060 average runoff in some basins projected to be between 5% and 60% below the 1995 runoff conditions (RCP8.5) (DELWP, 2020). The direction of change in runoff not as clear in the far east of the state, where projections show a reduced drying signal (for instance, 2065 runoff could be between 20% above or 30% below 1995 conditions).

A.2.4 Sea level rise

Sea levels have risen due to ice sheets on land melting and sea water expanding as it has warmed. It does not occur uniformly but varies locally due differences in coastal topography and nearshore processes. Tide gauges show that Victoria's mean sea level has been increasing, by between 1.6 and 5.3 cm/decade between 1931 and 2017.

By the 2030s, mean sea level is projected to rise by around 7-18 cm (RCPs 4.5/8.5) relative to 1986–2005. By the 2070s, warming of the atmosphere and oceans is projected to lead to an average sea level rise of 32-42 cm (RCPs 4.5/8.5). Upper range IPCC projections for global mean sea level rise by 2100 are as much as 1-1.5 m (IPCC, 2021).

Changes in sea level with climate change will likely exacerbate flooding in low lying coastal areas associated with high astronomical tides and/or storm surges (Figure 29). When combined, these may result in 100-year (1% AEP) storm tide reaching 2-3 m above mean sea level or more at some locations of the Victorian coast by 2100 (McInnes K. M., 2009). Upper range projected sea level rise could lead to what historically have been 100-year extreme sea level events recurring as frequently as every 1-2 years by 2100.

Sea level rise will be accompanied by rising groundwater levels in some coastal aquifers. It may also lead to the erosion and retreat of the coastline in areas of sandy, muddy or otherwise unconsolidated geology (Figure 29). The rate of retreat may be as much as 50-100 m for every metre of sea level rise.

[3] Reduction in groundwater recharge with climate change is projected for surface and unconfined aquifers (DELWP, 2016), but may not necessarily occur in unconfine aquifers.

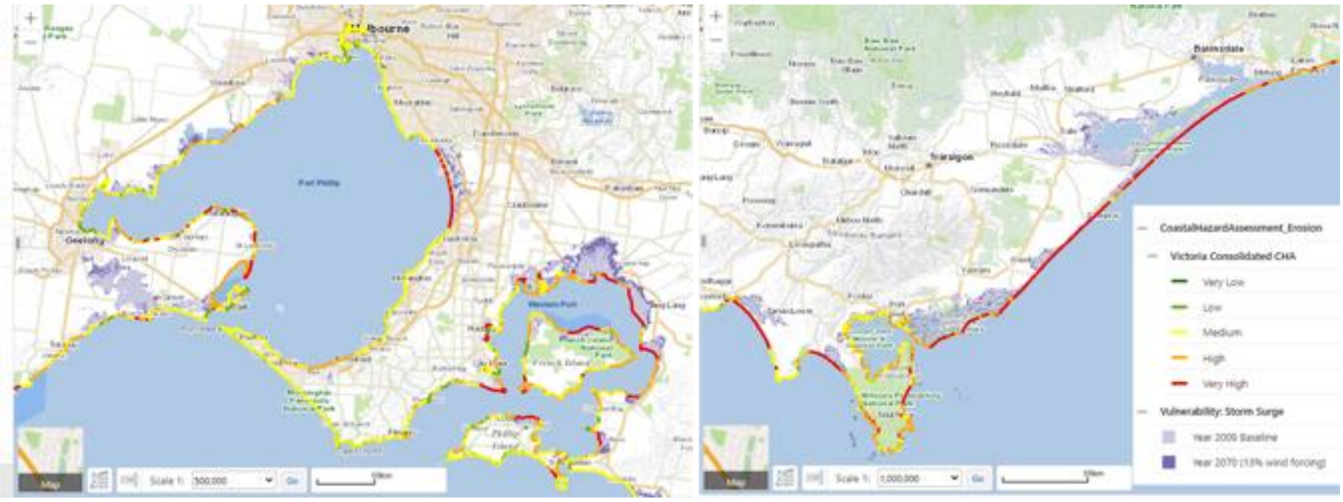


Figure 29: Modelled vulnerability to inundation during 100-year (1% annual exceedance probability; AEP) storm tide event for Port Phillip and Westernport Bay and Gippsland coasts – in 2009 and projected for 2070 (RCP8.5). Assessed vulnerability of coastline to erosion. The coastline is likely to retreat more rapidly with sea level rise in areas with higher vulnerability to areas with high. Source: Coast Kit (https://mapshare.vic.gov.au/coastkit/)

A.2.5 Bushfire weather

Fire weather conditions in Victoria are characterised by the grasslands and forest fire danger indices (GFDI/FFDI, respectively; McArthur 1966; 1967). These indices incorporate daily or sub-daily variation in temperature, humidity and windspeed, as well as a measure of seasonal rainfall deficit (for FFDI) or grass curing (for GFDI). Values of both indices scale to fire danger ratings that are used in public bushfire safety communications.

Climate change is projected to exacerbate fire weather conditions. Rainfall is projected to decline, which enhances drying of forest fuels and hastens the curing of grassy fuels. Higher temperatures and reduced humidity will increase the intensity of burning, help to exacerbate fire behaviour and potentially increase bushfire impacts.

The number of fire danger days in Victoria (where FFDI exceeds the 95^{th} percentile value for 1986-2005) are expected to increase in the future. By about 2090 (RCP8.5), the number of fire danger days is projected to increase by 10-20 per year throughout most of Victoria (Clarke, et al., 2019).

A.2.6 Carbon dioxide

Changes in atmospheric concentration of CO_2 (and other greenhouse gases) drive climate change and may also affect the durability of long-lived concrete structures. Under RCP4.5 CO_2 concentrations are projected to increase from about 400 ppm currently to about 540 ppm in 2100. Under RCP8.5, CO_2 concentrations are projected to increase to about 940 ppm by 2100. An increase in CO_2 levels may increase the rate of carbonation and the likelihood of carbonation-induced corrosion of reinforcing materials within reinforced concrete (Stewart, Wang, & Nguyen, 2010).

A.2.7 Humidity

Relative humidity is projected to decline with climate change, with greater change under higher emissions and in northern Victoria (Denson, Wasko, & Peel, 2021). By about 2070, relative humidity is projected to decline by up to 7% under RCP8.5 and up to about 5% under RCP4.5.

A.2.8 Wind

Average wind speeds are projected to decline slightly in response to climate change, with the effect most pronounced in autumn, winter and spring. The reduction in average wind speed is projected to be no more than about 5% by 2070 (Clarke, et al., 2019).

Projections of extreme wind conditions under climate change are less certain than for rainfall and temperature (Grose et al., 2015), due to fewer climate models providing wind speed estimates and the influence of local topography and vegetation. Clarke et al. (2019) provided projections of change in 20-

year return period (5% AEP) wind speeds. Regional climate models suggest either small increases or decreases in extreme wind speeds (~ ±1m/s), with some seasonal differences. Brown and Dowdy (2021) found that the frequency of conditions potentially giving rise to severe convective winds (which drive most wind-related damage to transmission infrastructure) in south-eastern Australia are projected to remain unaffected by climate change or reduce slightly in frequency.

A.3 Consideration of objectives in the context of climate change

Section 3.1 provides guidance on reframing existing or developing new objectives in the context of climate change impacts on the wastewater system. It is important to consider all service obligations (customer charter, economic and environmental regulatory) in the context of climate change during this process. The sections below provide additional guidance on customer and economics that could be considered during this process.

A.3.1 Customer and Economics

A.3.1.1 Customer Consultation

Victorian water corporations have established mechanisms for assessing customer expectations and responses to changes in service and delivery standards to comply with the ESC's PREMO water pricing framework. Customer focused outcomes are developed from customer engagement and verification. They also need to be measurable against agreed performance targets.

Engaging stakeholders and communities in planning for climate change should include wastewater systems. Such a process builds greater understanding of customer and community values and gains social licence for interventions or adaptive measures that mitigate or reduce climate risks. Key focus areas of a customer consultation process could include:

- Climate change beliefs
- Community expectations of water corporation in managing wastewater systems
- Providing information to customers so that they
  - are aware of the climate change impacts identified, their potential effects on wastewater system performance (including achievement of service obligations), the potential responses, the investment requirements and the risk-cost trade-offs; and
  - where there is a discretion, can make informed choices on performance objectives to be met, the appropriate level and timing of investment and their preferred risk position.
- Preference and willingness to pay for climate resilient wastewater systems
- Education of the risks to achievement of both legal and service obligations as a result of climate change e.g., the potential for an increase in asset maintenance due to a higher risk of pipe failure

Table 26 below gives an example of a customer value, its associated outcome and performance target, that could be identified through this process.

Table 26: Customer value and outcome example

Customer value	Outcome Example	Key performance target
Customers believe water corporations have a responsibility to limit the impact of climate change	Reliable and sustainable wastewater systems	• No deterioration in network hydraulic performance under the nominated climate change scenario (e.g., RCP4.5 or RCP8.5) – of meeting the WWF containment obligations and objectives • No deterioration in achievement of Dry Weather Flow (DWF) spills obligations and objectives under the nominated climate change scenario (e.g., as measured by a defined target in number or volume of DWF spills) • Aggregate service interruption times and duration of repairs and restoration of service • Reduction in carbon emissions by a set percentage each year.

Using the example shown in Table 26, water corporations' ability to achieve a target which reduces the number of spills from the wastewater system could be impacted by changes toto rainfall IFD.

Rehabilitation, modifications or upgrades to the wastewater system are likely to be required in the future to manage the impacts of climate change. This would have an associated capital or operating expenditure that would need to be clearly linked back to the proposed outcome to demonstrate how the projects would deliver improved customer value.

The most recent WSAA 2020 Asset Management Customer Value (AMCV) project reports, notably the of Leading Practices conference component, provide relevant examples of leading practice customer consultation (WSAA, 2016).

A.3.1.2 Customer Charter

A water corporation's customer charter outlines the commitments, responsibilities and standards of service that they provide to customers. Standards of service may vary between water corporations.

Climate change is likely to impact water corporations' abilities to achieve their customer commitments. An example of typical Customer Charter commitments and the resulting impacts from climate change are show in Table 27.

Table 27: Typical customer charter commitments that could be impacted by climate change

Example Customer Charter Commitment	Climate hazard condition and potential impacts	Potential Climate Change Effects	Impact on Businesses achieving Customer commitments
Sewerage service is not interrupted more than 2 times in a year *Sewerage interruptions will be contained within 4 hours of notification*	• Change Temperature • Rainfall: seasonal to annual • Relative humidity	Climate hazard conditions • Drier climate Potential impacts • Drier Soils • Higher sewage concentrations • Corrosion • Decreased sewer flows	Service and ability to remediate the network could be impacted by the following: • Increased failures due to tree roots. • Reduced flows caused by water restrictions resulting in lower scouring velocities and solid/sediment retention within sewers. • Temperatures, relative humidity and residence time increase likelihood of H_2S generation resulting in corrosion.
Less than 2 sewer spills from the system on to a property per year	• Rainfall IFD • Sea level	Climate hazard conditions • Heavy rainfall Potential impacts • Surface flooding • Increased peak sewer flows • Groundwater and sea water intrusion	Frequency of spills could increase due to the following: • Change in flood impacts to es creating surcharging in the upstream network. • Disruption to power supply caused by extreme weather. • Inadequate system capacity . for peak flows

A.4 Characterising future conditions for climate change vulnerability, risk and impact assessments

Climate change vulnerability, risk and impact assessments are informed by climate change projections, many of which are developed from baseline historical data adjusted for the adopted climate change scenarios. Techniques for developing projections depend on the type of assessment being conducted and the tools being used. This appendix provides guidance on how to prepare climate change projections for use in climate change vulnerability, risk and impact assessments that are relevant to wastewater systems.

A.4.1 Climate change projection timeframes

The climate change projection timeframe(s) used in vulnerability, risk and impact assessments and design or planning activities based will depend on data availability, planned asset life and/or planning timeframe. For complex infrastructure (e.g., wastewater treatment plants) with multiple components with differing asset lives, climate change projections for multiple timeframes may be considered.

Climate change factors are typically available in public sources for the period 2030 to 2090 (as averages for the 20-year period centred around the date referred to) in either 10 or 20-year time slices. Some sea level rise and storm tide projections are available for 2100.

There are currently no public climate change projection data sets that extend beyond 2100. Where 2100 scaling factors are required, they may be extrapolated from earlier periods. Extrapolations should not go beyond 2100.

Assessments, planning and/or design for new assets with design lives that extend well beyond 2100 may need to commission bespoke analyses for source projections from private sector providers.

Consistent with planning timeframes of water corporation Urban Water Strategies, climate change projections/factors published in the Water Availability Guidelines are provided for 2020, 2040 and 2065 and can be interpolated for intervening timeframes.

A.4.2 Climate change projection reference period

Climate change projection reference periods provide a baseline from which to project climate change and its potential impacts. They help to place climate change in the context of recorded natural climate variability and are important for consistency and repeatability in climate change vulnerability, risk and impact assessments.

The selection of a suitable reference period involves trade-offs between the period being long enough to capture natural climate variability and it being short enough to avoid the confounding effects of trends driven by climate change. The standard reference period for AR5 climate change projections is 1986-2005. An updated reference period of 1995-2014 is also included in AR6.

The Water Availability Guidelines establish two reference periods for streamflow and water availability applications:

- Post-1975: which is used as the reference period for applying the climate change projections recommended in the *Guidelines*
- Post-1997: which assumes that the climate patterns observed since the Millennium Drought permanently continue.

They also provide advice on the use of stochastic data analysis to further extend the climate change projection reference period and better characterise inherent natural variability.

Use of a 40-year reference period (1976-2015; also centred around 1995) may be appropriate in some instances (particularly for temperature), to better reflect climate variability and conditions that have already been experienced.

A.4.3 Sources of data for developing climate change projections

The following describes relevant public data sources for climate change scaling factors for use by Victorian water corporations in developing climate change projections. Further details of when the sources may be appropriate to use are provided in Table 28.

- *Guidelines for Assessing the Impact of Climate Change on Water Availability in Victoria:* this guideline provides climate change factors for temperature, potential evaporation, rainfall and runoff and groundwater recharge to support the Victorian water sector assess the impact of climate change on water availability, supply and demand. The information is summarised by surface water catchment. Data is available for 2020, 2040 and 2065 and RCPs 4.5 and 8.5. Climate change factors are provided for 10 (low), 50 (medium) and 90 (high) percentile outcomes from the suite of 42 climate models used.
- Victorian Climate Projections 2019 (VCP19): the technical report (Clarke *et* al., 2019) and data set provide access to and analysis of downscaled climate change projections for Victoria. The dataset and report are based on new 5 km-resolution downscaled climate model outputs that draw on AR5 climate models and emissions scenarios. Data are provided in spreadsheet format for 10 regions and include climate change factors for RCPs 4.5 and 8.5 at 2030, 2050, 2070 and 2090. Climate change factors are provided for 10, 50 and 90 percentile values from the ensemble of climate models used.
- Victoria's Future Climate Tool (VFCT): map-based tool that may be used to interact with VCP2019 and other baseline climate and climate change projection information. Data can be viewed/downloaded for the state, various administrative units or user-defined polygons. VFCT also provides access to basic coastal hazard projections. In addition to coastal hazard data, climate change projections are available for maximum, minimum and average temperature, rainfall and relative humidity for RCPs 4.5 and 8.5- and 20-year time slices from 2030-2090.
- CoastKit: a map-based tool that brings together marine and coastal data, images and resources. The information relates to multiple themes, of which coastal assets, infrastructure and shorelines, coastal hazard assessments, bathymetry and topography are likely to be most relevant to wastewater systems. The tool has data on existing coastal conditions and, under the coastal hazard assessment tab, data on projected sea level rise and storm surge conditions. Sea level rise and storm surge data are for 2050, 2070 and 2100, with sea level rise based on the upper range projection from AR4. CoastKit includes results from state-wide and local climate hazards assessments.
- Australian Rainfall and Runoff data hub (ARR): tool that allows for access to design inputs for flood estimation in Australia. It provides "interim" climate change scaling factors for heavy rainfall for any location in Australia. It also include technical reports and access to data on historical climate conditions. Climate change scaling factors are provided for 10-year time slices from 2030-2090 and for RCPs 4.5, 6 and 8.5. Scaling is based on CC scaling at 5% change in heavy rainfall intensity per degree of global warming for all storm durations and severities.

A summary of the data and sources for eight climate hazard conditions that are the focus of these guidelines is provided in Table 28:. The data sources may be used to find climate change scaling factors, develop climate change projections and assess vulnerability, risks and potential impacts. Table 28 also explores the level of confidence that exists in relation to the climate change description and provides commentary that water corporations should consider when understanding the uncertainty of climate projections.

Water corporations should also consider that projections may vary between data sources and that very high spatial/temporal resolution data is not necessarily better. The Water Availability Guidelines offer a relevant example comparing VCP19 and Victorian Climate Initiative (VicCI) guideline projections. Uncertainty and variability in projections is also explored in *Victoria's Water in a Changing Climate* (DELWP 2020) which compares projected changes from a range of sources and notes that "the different projection products (from different ensembles of GCMs and/or dynamic downscaled products) and methods do not necessarily converge to a narrower range of change".

Key sources of data on existing conditions to establish baseline or reference period conditions are listed in Table 29. The table addresses a wider range of wastewater system issues that may be influenced by climate change (column 1). It identifies the key climate change hazards (column 2) and then lists the key climate or climate-change related inputs required for analysis (column 3). Column 4 lists the types of outputs that may be generated from climate change impact analysis for each design issue. Key climate or climate-related data sources that may be required for the analysis are given (with hyperlinks) in column 5.

Table 28: Level of confidence in seasonal and daily time step changes in climate from global climate models (GCMs), for water resource planning applications (adapted from Grose et al. (2015a) and Timbal et al. (2015)

Climate Hazard Condition	**Climate change description**	**Level of confidence that this change will occur**	**Comments**	**Recommended data source**
Heavy rainfall events	Intensity of heavy rainfall events will increase.	High with regard to direction of change, but medium confidence in the magnitude of the change	The magnitude of the change cannot reliably be projected as some smaller scale processes associated with extreme events are not well represented by GCMs.	Australian Rainfall and Runoff Guidelines Guidelines for assessing the impact of climate change on water availability in Victoria provides advice on how to consider changes in intense rainfall events within the context of an overall drying climate.
Increased air, ground and water temperature:.	Increase in the temperature reached on the hottest days, the frequency of hot days and the duration of warm spells.	Very High	While confidence is very high, confidence in the exact magnitude of the temperature increase, particularly at a local scale, is low.	Guidelines for assessing the impact of climate change on water availability in Victoria Victoria's Future Climate Tool has additional information on heatwaves frequency and duration
Drier climate:	Increase in potential evaporation rates in all seasons.	High with regard to direction of change, but medium confidence in magnitude of the change		Guidelines for assessing the impact of climate change on water availability in Victoria
	Time spent in drought (rainfall deficiencies) will increase over the course of the 21st century and the frequency and duration of extreme droughts will increase.	Medium	Hope et al. (2015b) states drought durations in the GCM outputs over the 21st century are all shorter than the Millennium Drought.	Guidelines for assessing the impact of climate change on water availability in Victoria

Climate Hazard Condition	Climate change description	Level of confidence that this change will occur	Comments	Recommended data source
	Rainfall decreases in winter and spring.	High	Hope et al. (2015b) states that, “there are a number of reasons to expect that projected cool season rainfall deficits may be under-estimated by current climate models, particularly for the winter months”, notably that the models, “do not capture the magnitude of the observed trends in the sub-tropical ridge” that are associated with cool season rainfall changes in Victoria.	Guidelines for assessing the impact of climate change on water availability in Victoria
	Little change in autumn rainfall.	Low for southern Victoria	Grose et al. (2015a) states that substantial decreases in autumn rainfall are also plausible. Timbal et al. (2015) does not specifically comment on the level of confidence in changes in autumn rainfall for northern Victoria.	Guidelines for assessing the impact of climate change on water availability in Victoria
Sea level rise:	Sea level rise	High with regard to the direction of change but medium confidence in the magnitude at local/regional scale	By the 2070s, average sea level rise of 32-42 cm (RCPs 4.5/8.5) (CSIRO and BoM, 2015). Upper range IPCC projections for global mean sea level rise by 2100 are as much as 1-1.5 m (IPCC, 2021).Sea level rise not only results in changes in mean sea level but can also change the frequency and intensity of extreme sea level events, such as storm tides that occur when high tides combine with strong winds and low-pressure systems.	Coast Kit (https://mapshare.vic.gov.au/coastkit/) or data from a local coastal hazards assessment if available for the area of interest.
Bushfires:	Bushfire weather	Reasonably high confidence that fire weather conditions will be exacerbated (longer and more intense season)	Climate change is projected to exacerbate fire weather conditions, likely to result in longer and more intense fire seasons. By the 2050s Victoria is likely to experience double the number of high fire danger days (Clarke et al., 2019).	Given the complex nature of fire risk, water corporations are recommended to utilise the Bureau of Meteorology's historical FFDI values and assume a doubling of the very high FFDI days by the 2050s. This would provide a reasonable basis from which to assess risk that can be supplemented by more locally specific research, if available, for the area of interest (e.g., Clarke et al 2021 Sarah Harris CFA work with Tim Brown).

Climate Hazard Condition	Climate change description	Level of confidence that this change will occur	Comments	Recommended data source
Reduced humidity:	Humidity	Medium confidence	Relative humidity is likely to continue to decline with rising temperatures (Denson et al 2021).	Victoria's Future Climate Tool
Wind:	Wind	Low confidence	Regional climate models suggest either small increases or decreases in average and extreme wind speeds. Future changes in thunderstorms are relatively uncertain for lightning, hail, tornados, and extreme wind gusts (Clarke et al., 2019).	No change - historical data sufficient

Table 29: Wastewater system issues influenced by climate change.

Wastewater system design or planning issue	Applicable climate change hazard(s): from Appendix A.1	Climate-related design parameters &/or planning inputs		Climate or other key data source(s)
		Climate inputs	Analysis outputs	
Peak sewer flows *Sewer network* *Pump stations* *Treatment plants*	Heavy rainfall Drier climate Sea level rise	Rainfall intensity-frequency-duration (IFD) for design storm events Groundwater level Sea level Evaporation	Sewer inflow (during storm event) Groundwater infiltration	Historical precipitation observations: Bureau of Meteorology (BoM http://www.bom.gov.au/climate/data/), SILO https://www.longpaddock.qld.gov.au/silo/ Design rainfalls (IFD) and climate change projections for design storm events (temperature increases and rainfall scaling factors): Australian Rainfall & Runoff data hub (ARR www.data.arr-software.org/data.arr-software.org/) Victorian streamflow and groundwater observations: Water Measurement Information System (WMIS www.data.water.vic.gov.au/) Advice on how to applying rainfall and runoff climate change projections to groundwater recharge: DELWP water availability guidelines https://www.water.vic.gov.au/climate-change/adaptation/guidelines Current and projected sea level rise and coastal flooding: CoastKit (https://www.marineandcoasts.vic.gov.au/coastal-programs/coastkit)
Average sewer flow volume and concentration *Sewer network* *Pump stations* *Treatment plants* *Water recycling* *Biosolids*	Drier climate Sea level rise	Seasonal/annual rainfall & evaporation Groundwater level Sea level	Groundwater infiltration Sewer inflows & concentration	Historical precipitation observations: BoM, SILO Average annual/seasonal rainfall and potential evaporation climate change scaling factors: DELWP water availability guidelines https://www.water.vic.gov.au/climate-change/adaptation/guidelines, Future climate projections for average annual/seasonal rainfall (max, min, mean and extremes) and potential evaporation Victoria's Climate Projections (VCP) 2019 https://www.climatechangeinaustralia.gov.au/en/projects/victorian-climate-projections-2019/, Victoria's Future Climate Tool (VFCT) https://vicfutureclimatetool.indraweb.io/ Victorian streamflow and groundwater observations: WMIS Applying climate change projections to groundwater recharge: DELWP water availability guidelines Current and projected sea level rise and coastal flooding: CoastKit
Groundwater intrusion (including by seawater) *Sewer network* *Pump stations* *Treatment plants*	Drier climate Sea level rise	Seasonal/annual rainfall & evaporation Groundwater level Sea level	Groundwater infiltration	Precipitation, evaporation historical observations: BoM, SILO Climate change scaling factors: VCP2019, VFCT Groundwater current conditions: WMIS Climate change scaling factors for groundwater recharge: DELWP water availability guidelines Current and projected sea level rise and coastal flooding: CoastKit
Sewer (internal) corrosion and odour generation *Sewer network* *Pump stations*	Temperature Humidity Drier conditions	Ambient temperature & humidity	Sewer inflows, concentration and residence time Sewer micro-climate: temperature, humidity H_2S generation Sewer corrosion	Temperature, precipitation, evaporation historical observations: BoM, SILO Future climate projections for average annual/seasonal temperature (max, min, mean and extremes) and relative humidity: VCP2019, VFCT
Odour dispersion *Sewer network* *Pump stations* *Treatment plants* *Biosolids*	Wind Temperature Humidity	Ambient temperature & humidity Average wind speed	Sewer H_2S /odour generation Incidence of temperature inversions Odour dispersion	Historical observations of wind, temperature, relative humidity: BoM, SILO
Extent of surface flooding *Sewer network* *Pump stations* *Treatment plants* *Water recycling* *Biosolids*	Heavy rainfall Drier climate Sea level rise	Rainfall IFD for design storm events Sea level rise	Flood extent, depth, flow	Historical observations of precipitation: Bureau of Meteorology (BoM) Design rainfalls (IFD) and climate change projections for design storm events (temperature increases and rainfall scaling factors): Australian Rainfall & Runoff data hub (ARR data.arr-software.org/) Current and projected sea level rise and coastal flooding: CoastKit Flood extent: Victorian Flood Database www.data.vic.gov.au, Floodway and Land Subject to Inundation overlays www.data.vic.gov.au

Wastewater system design or planning issue	Applicable climate change hazard(s): from Appendix A.1	Climate-related design parameters &/or planning inputs		Climate or other key data source(s)
		Climate inputs	Analysis outputs	
Root ingress during drought/dry periods *Sewer network*	Drier climate	Seasonal/annual rainfall & evaporation Groundwater level		Historical observations of precipitation, evaporation: BoM, SILO Climate change scaling factors: DELWP water availability guidelines, VCP2019, VFCT Groundwater current conditions: WMIS Climate change scaling factors for groundwater recharge: DELWP water availability guidelines
Infrastructure durability *Sewer network* *Pump stations* *Treatment plants* *Water recycling* *Biosolids*	Temperature Carbon dioxide Wind Bushfire weather Solar radiation	Seasonal extreme high and average temperatures Atmospheric CO_2 concentration Extreme wind speed Daily and sub-daily rainfall, temperature, humidity, windspeed Solar radiation	Forest & Grasslands Fire Danger Index Concrete carbonation rate	Historical observations of temperature, precipitation, humidity, wind: BoM, SILO Climate change scaling factors: VCP2019, VFCT, Electricity Sector Climate Information (ESCI) project (www.climatechangeinaustralia.gov.au/en/projects/esci/) Bushfire prone areas mapping: www.data.vic.gov.au Bushfire Management Overlay: www.data.vic.gov.au
Resilience of mechanical and electrical equipment *Pump stations* *Treatment plants* *Water recycling* *Biosolids*	Temperature	Extreme high temperature		Historical observations of temperature: BoM, SILO
Wastewater treatment process efficiency *Treatment plants*	Temperature Drier climate Sea level rise	Seasonal extreme high and average temperatures Seasonal/annual rainfall & evaporation Groundwater level Sea level	Groundwater infiltration Sewer inflows & concentration	Historical observations of precipitation, evaporation, temperature: BoM, SILO Climate change scaling factors: DELWP water availability guidelines, VCP2019, VFCT Groundwater current conditions: WMIS Climate change scaling factors for groundwater recharge: DELWP water availability guidelines Current and projected sea level rise and coastal flooding: CoastKit
Recycled water use *Water recycling*	Drier climate Heavy rainfall	Daily/monthly/annual rainfall & evaporation Rainfall IFD for design storm events	Recycled water irrigation rate and winter storage requirements	Historical observations of precipitation, evaporation: BoM, SILO Climate change scaling factors (monthly rainfall & evaporation): VCP2019, VFCT Climate change scaling factors (heavy rainfall): ARR
Wet weather release of recycled water to receiving environment *Water recycling*	Drier climate Heavy rainfall	Daily/monthly/annual rainfall & evaporation Rainfall IFD for design storm events	River flows in receiving environment Winter storage requirements	Historical observations of precipitation, evaporation: BoM, SILO Historical river flows: WMIS Climate change scaling factors (monthly rainfall & evaporation): VCP2019, VFCT Climate change scaling factors (heavy rainfall): ARR Climate change scaling factors for catchment runoff: DELWP water availability guidelines
Sludge drying rates *Biosolids*	Drier climate	Monthly/seasonal/annual rainfall & evaporation		Historical observations of precipitation, evaporation: BoM, SILO Climate change scaling factors: VCP2019, VFCT

A.5 Supporting tools and applications to assess impact of climate change

A.5.1 Data

This section covers the data governance framework and the value of data and its limitations in underpinning policy decisions and planning and its use in analytical tools/models required to assess climate change impacts in wastewater systems. It provides general context and important matters to be considered when gathering and using data. Data needs to be relevant, sufficient and of appropriate accuracy for assessing climate change impacts.

This is an important prelude to the discussion on supporting tools that may be used to assist in assessing climate change impacts, in decision making, or meeting service obligations and objectives.

Supporting tools discussed in the section below include:

- process-based models (often available as part of software packages)
- empirical models and frameworks for risk screening,
- statistical models, and
- machine learning algorithms (discussed in Section 3.3.4).

These tools, which generate information from data, are often linked to asset management and decision support systems using other tools such as smart metering, digital twins, and data management infrastructure.

This section defines support tools as models or frameworks that can assist with:

- Acquiring and managing data
- Generating information from data
- Feeding data into decision support systems

Data collected by water corporations can include asset installation records (model and manufacturer, geo-location data, start up and commissioning records, etc.), operational performance monitoring (outputs from sensors and monitoring devices, etc.), asset management records (maintenance task, cost, frequency, failure cause, etc.), and other information related to the lifecycle of assets and infrastructure.

The quality of the data collected, and the methods of recording and storing it can impact the usefulness of the data for application in tools and for decision-making purposes.

Tools such as machine learning algorithms require large volumes of data that is consistent, has accurate metadata, and is stored properly to be able to perform predictive analytics tasks (use past data to predict the future). Poor quality data requires labour intensive processing and cleansing tasks to improve the data.

The quality of data with respect to a particular management issue is affected by:

- Available technology for data collection
- Data source(s) and their relevance to the management issue
- Accuracy of data
- Relevancy of data
- Completeness of data (gaps, duplications)
- Consistency of data (consistent data fields such as units of measure, timescale, degree of accuracy)
- Validity of data (version control/data collection methods)
- Timeliness of data (real-time data, relevant timeframes)
- Data collection/harvesting framework and structure
- Data collection and storage tools (manual input, automation)

- Understanding and appropriate use of data

Data quality and confidence can be improved through the implementation of a data governance framework. McKinsey three key components for best practice data governance model are shown in Table 30 (Petzold, Roggendorf, Rowshankish, & Sporleder, 2020).

Table 30: Best practice data governance model (Petzold, Roggendorf, Rowshankish, & Sporleder, 2020)

No	Best Practice Data Governance	Description
1	Data management office:	A leadership team that defines the data strategy (policy and standards) and ensures coordination of data management activities and the systematic and consistent application of the strategy.
2	Data leadership by domain	Allocation of roles and accountabilities for the day-to-day execution of data strategies and ownership of data.
3	Data council	Bringing domain leaders and data management office together to align data strategy and priorities with corporate strategy, approve funding, and address issues.

There are two key overarching aspects to data and information:

1. Tools to efficiently and accurately collect data and information that is to be used for decision making, and
2. Development of a framework for using the data for analysis and decision making which aligns with leading practice governance (business objectives, accountability, transparency) comprising:
    a. Back-end databases:
        - Technology used to collect data should be considered, e.g., wastewater database learnings from United States Environmental Protection Agency (US EPA) initiatives.
        - Identification and prioritisation of data linked with decision-making purposes.
        - Accessibility of data and information.
        - Data is compliant (privacy regulations, data is trusted (including third party external data, primary data).
    b. Data visualisation tool (e.g., Power BI).
        - Presentation of data and outcomes of analysis to senior management, Boards, and stakeholders.
    c. Monitoring regime and platforms (e.g., monthly in this context).
        - To ensure consistency of measurement and appropriate tracking of change and progress of initiatives (to establish effectiveness).
    d. Performance assessment (of climate change effects) – predicted and actual.
    e. Tools for effective reporting of assessment outcomes and data governance (evaluation and management of data for effective policy decision making).

In the context of data and information required to quantify the impacts of the climate change effects on the various components of the sewerage system the following should be considered:

- The materiality of the biophysical factors related to climate change on the wastewater system component behaviour and performance; and
- The rate of change of those effects to inform the linkages and alignment with the relevant planning and decision-making timeframes. This would consider:
    - Extent of variability versus extent of change.

- Extremes versus averages
- Longer term strategic planning horizons which are more likely influenced by climate change effects in the second mentioned above (extent of change, averages) which are typically indicated to have a material impact over two or three decades based on current understanding; and shorter-term tactical planning horizons (typically say 5 – 10 years) which needs to take account of variability and extremes.

Consideration should also be given to the data collection and governance frameworks that DELWP, other performance reporting entities and any water corporations have implemented.

It is of note that the US EPA has developed a series of guidance and technical papers for the collection and entry of data related to pollutant discharges. *[See https://www.epa.gov/compliance/data-entry-guidance-and-technical-papers].*

A.5.2 Limitations of data

For sewerage systems the quality, accuracy, variability and repeatability of data gathered will differ depending on what component and aspect of the sewerage system is being considered. This is especially important in informing the development of decision tools.

For example, the monitoring and metering of sewage flows can typically be estimated within +/- 5% and with reasonable repeatability, and sewage depths more accurately. However, sewage quality parameters (e.g., BOD/COD, total suspended solids) and sewer gas space data (e.g., H_2S and other gaseous compounds, relative humidity, odour unit levels) typically can only be measured with much less accuracy and repeatability. This is attributable to the difficulty in obtaining truly representative samples (whether taken by a person or automated) particularly in a live sewer environment, the inherent variability diurnally and seasonally and finally in the difficulty in test procedures themselves (even though standard test procedures exist and are used). This is in contrast to air quality monitoring for which relatively accurate real time sensor data can be obtained.

When considering climate change impacts, this variability needs to be weighed against the magnitude of the effects of relevant climate change bio-physical variables and their materiality.

The frequency of data collection should be linked to the planning, operational and decision-making timeframes and the timing of climate change impacts.

Common issues with data to be used for developing statistical approaches or machine learning tools are that:

- the data collected did not fully contemplate the purpose for which it was to be used including to support the development of algorithms and/or decision making (i.e., incorrectly recorded or missing service and structural failure information or asset management characteristics in asset management databases).
- the data collected did not have a focus on accuracy, completeness and consistent interpretation of guidance provided on definitions for the aspects and form of information sought, including human error.
- significant data cleansing exercises of historical data is required to ensure it is fit-for-purpose in developing algorithms including for assessing the impacts of climate change variables. This needs to be remedied with a future focus to ensure that the type and form of data required is well understood and is sufficiently complete and accurate to enable reliable outputs from models developed and used to assess climate change impacts.

Limitations of models

The frequency of modelling to establish and monitor the quantitative impacts and trends of climate change variables should be linked to the types of planning (strategic, tactical, operational level), operational and decision-making timeframes and the timing, variability and rate of climate change impacts themselves.

A.5.3 Software tools

Software tools or models can be divided into static or dynamic tools.

A static software tool can be defined as one where the parameters are given (parameters defining boundary or initial conditions), the model will produce an output/outcome. The outcome is then utilised 'as is' for further analysis.

A dynamic tool is one where the parameters can vary (and be measured e.g., through sensors) and where some output/outcome produced by the model is reused as an input to minimise or maximise a global outcome (optimised pump, spills or leakage, global cost/time). A natural consequence of a dynamic tool is that multiple models can be bundled in the same process (odour vs flow capacity). Traditionally, these components were established as individual supporting tools where each was separately developed and run sequentially with the outputs from one feeding as inputs into another. This was potentially cumbersome, difficult, and open to the risk of errors.

Figure 30 outlines three examples of static and dynamic tools or models. In these examples, each model is investigating sewer network capacity, subject to fixed topographic boundary conditions, and constrained by gravity flow modelling.

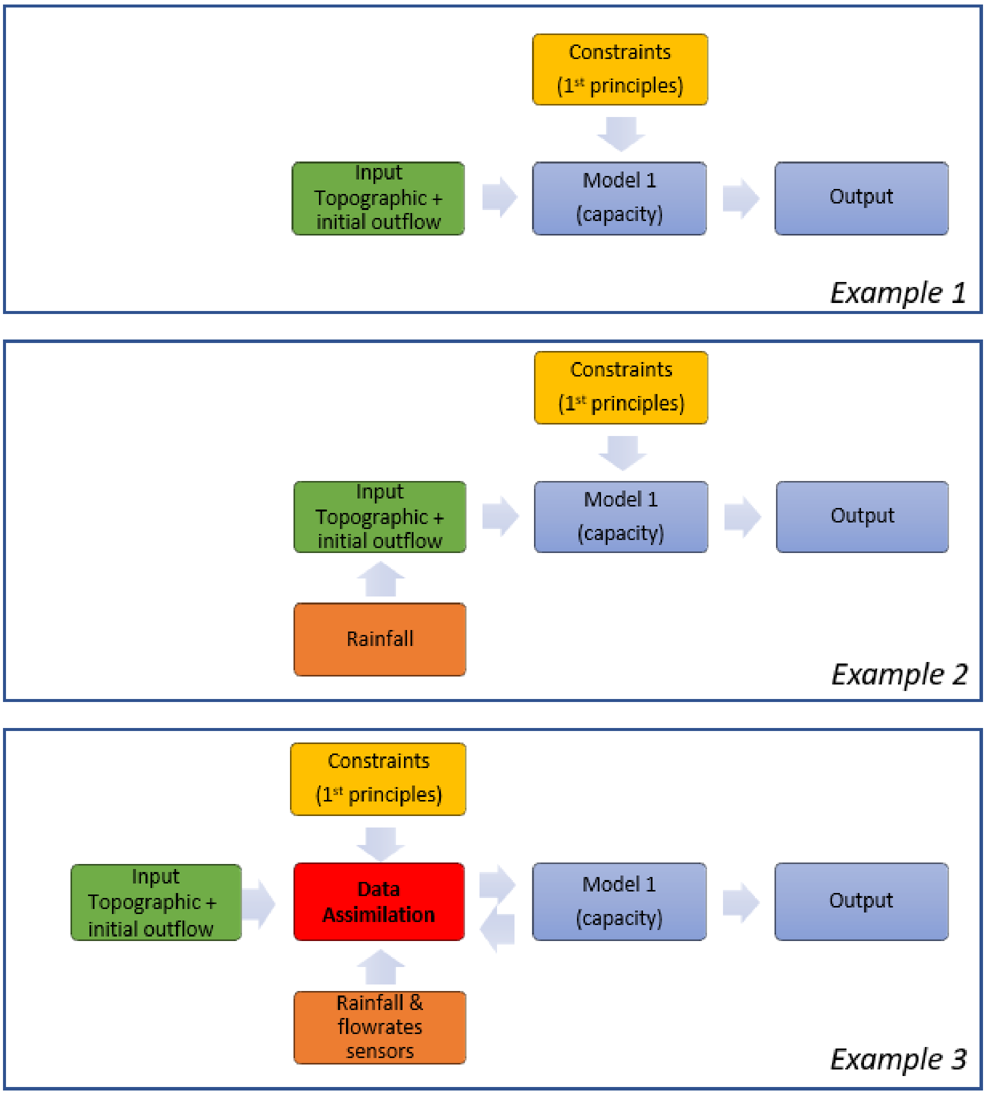


Figure 30: Examples of the form of models and tools

The three models vary in complexity and application. Several comments can be made about the features of these three forms of models.

Example 1:

- This example depicts a static model in a singular network modelling application.
- Wet weather models are sometimes calibrated to a precipitation event.
- Inputs: catchment information (hydrology, population), network information (including controls, standard peaking factors and diurnal patterns).
- **Limitations**
    - Limited validity (variation in the inputs or model deterioration)
    - Forecasts are not provided

Example 2:

- This example also depicts a static model in a singular network modelling application with the potential to be dynamic.
- However, in this case there is integration of external data, including pump station operation, wet well levels and overflow monitoring. This informs improved calibration and can enable models to be more dynamic with analysis of specific network/precipitation events.
- **Limitations**
    - Limited validity (variation in the inputs or model deterioration)
    - Forecast provided based on the external events

Example 3:

- This example depicts a dynamic model where integration of data and outputs from other sources, including assessments of climatic factors and other disruptive events that can impact network capacity are included.
- Data cube and other AI/ML (artificial intelligence/machine learning) solutions can be applied to assess impacts on network model boundary conditions from multiple and other climatic variables. Sensitivity assessments of network models to determine wastewater assets most vulnerable to impacts of climate change.
- The model is regularly updated through a regularisation process (data assimilation strategy such as 4D-Var, or Ensemble Kalman Filter)
- Forecast are provided

The timeframe of execution is an important consideration to choose whether a study should use static or dynamic tools. This would involve a trade-off between resources available and the nature of the risk and importance of the decisions which the tool/model is informing. If some of the variables are slow moving, then a static tool may be acceptable if repeated or run regularly. For instance, planning for long term simulation with various scenarios can be left static and use to guide or give specific constraints, whereas short term simulation can be thought to be more reactive and day-to-day compliant (similar to a live model).

A.5.4 Network Modelling, Monitoring, and Assessment

- Key to the sewer network impact assessment and monitoring, is the representation of the actual assets, through a model of the network. The models can vary in complexity with or without sensors to monitor some variables, as indicated previously. The different aspects for consideration include:
- Network modelling solutions: advancements in wastewater network modelling solutions enable integration of catchments and stormwater infrastructure for assessment of wastewater network response to changes in rainfall and sea levels.
- Monitoring: time-series monitoring of levels at junctions and wet wells, pump station operation and performance, environmental conditions, and demand.

- Analytical and predictive solutions for the assessment of network performance and behaviour in response to climate factors.
- Maturity modelling: readiness assessment and identification of people, processes and technology needed for successful implementation of modelling, monitoring and analytical solutions for analysis and response planning for climate change impacts.

A.5.5 Sewage Treatment and Effluent Reuse

Effective process models for sewage treatment plants include proprietary software packages such as BioWin™ and Sumo™.

These software packages are used to simulate sewage treatment plant processes under a variety of conditions. They can provide information that can allow decision makers to determine capital and operating costs.

Once calibrated and validated they can be used to assess the biological process treatment performance in its entirety, or for elements of the system, considering for example technology upgrades, changes to aeration or chemical usage. These tools can be used to assess process performance (e.g., nutrient removal, solids generation) under a range of scenarios which take account of climate change impacts on influent sewage quality changes, influent flow variability (e.g., flow peaking factors affecting hydraulic and solids residence times) and process parameters (e.g., seasonal and longer-term temperature variability, fractionation parameters).

Another key tool available is the Water Environment Federation (WEF) Manual of Practice No FD-8 (Clarifier Design) which details the processes for undertaking state of point analysis for secondary clarifiers as part of the treatment train mixed liquor solids from treated effluent. It specifies for secondary clarifiers the acceptable target areal hydraulic loading rates and solids loadings rates (solids mass flux rates as function of mixed liquor solids concentrations) ensuring solids removal adequacy to meet treated effluent quality objectives. The safety factors identified will need to be reviewed over time to effectively take account of seasonal variations, increased sewage/mixed liquor/treated effluent temperatures and any increased risk of temperature gradients within secondary clarifiers.

Collectively, these tools can identify and quantify climate change impacts on treatment plant performance. They can be used to test the effectiveness of mitigation strategies to ensure process performance is maintained within acceptable bounds to meet operating licence and other objectives and obligations.

Software packages for the modelling of effluent reuse and disposal, and air drying of solids are also available. An example of this software is the MEDLI tool developed collaboratively by the Queensland Department of Primary Industries. This software allows the user to understand and assess irrigation schemes by evaluating "the quality and quantity of effluent available, climate, storage and treatment, irrigation frequency and amount, flow paths of water, nitrogen, phosphorus and salt components and plant growth" (The State of Queensland (Department of Environment and Science), 2018). The software can be used to design and test the long-term viability of an effluent treatment and irrigation scheme, identify weaknesses in the scheme and establish the need for mitigation initiatives (e.g., greater volume storages to address more intense rainfall events and greater temporal variability, and/or greater irrigation or solids drying areas).

While software tools are available, bespoke tools using first principles transport phenomena analytical processes should be considered using as inputs local/regional rainfall and evapotranspiration patterns as informed by the Guidelines.

A.5.6 Digital twin

The digital twin model is a digital or virtual representation of an asset, asset system or facility that simulates the performance of the asset, asset system or facility over a period of time, e.g., the operation of a wastewater treatment plant to simulate the performance of the process or asset condition tracking by utilising real-time data. The information gathered from the digital twin can be used to inform decision-making by assisting the user to understand the current state or forecast the future. A spectrum of liveness can be implemented within the digital twin

A digital twin is a tool that is now being widely developed and used for BAU operating purposes to optimise cost and performance, including for sewerage network and treatment plant operation. This tool could be used as a platform, or incorporate algorithms, to understand the impacts of changes in future operating conditions including those due to climate change. While the main strength of a digital twin is its use to facilitate more effective short-term decision making, it could be used for trending operating conditions (and their consequences) that may be impacted by climate change to inform longer term decisions. Using the digital twin for assessing the impacts of climate change would be a decision for each water corporation noting the difference in time scales in that the climate change conditions are slow-moving variables and digital twin development has been focussed at least initially on improving short term performance.

A.5.7 Asset Management tools: Preventative Maintenance and Hypervision (Data Visualisation)

Digital twin models can be used to support inspection and condition assessment of high-risk in-service assets by utilising remote inspection techniques to locate, geo-tag and label defects. The information gathered can be used to inform intervention and renewal decisions.

The benefits of using remote inspection techniques are:

- Eliminated need for people to enter high risk environments – improve personnel safety
- Reduced cost of travel, inspection time,
- Improved data quality

Digital twin benefits are:

- Visualisation of asset, tracking of change in condition over time, analysis and simulation of changes
- Continuous update with data from multiple sources – dynamic model
- Informed decision making – predictive maintenance of in-service assets.
- Analysis of condition data, and monitoring of entire system to prevent failures/defects, reduce downtime, and develop plan for future design/upgrade using simulation

A.5.8 Odour and Corrosion Models

A.5.8.1 H2S generation and sewer ventilation models

There are several odour and corrosion tools that can be used to estimate:

- H_2S generation and release to the sewer gas space in a sewer network,
- impact of different sewer ventilation conditions on H_2S concentration in sewer gas space and potential for foul air release to the atmosphere,
- corrosion rates in sewers,
- the extent of odour dispersion in ambient air to be able to meet environmental or EPA licence obligations.

Each of the odour and corrosion models have inputs which are directly or indirectly related to key climate hazard conditions. This means the challenge is to ensure that the change in input variables in the longer and shorter term is quantified to appropriately reflect the climate hazard conditions. Once the climate hazard conditions and changes to the model inputs have been established the materiality of the impacts (in this instance) on corrosion and odour in the sewerage system can then be quantified.

The model output information is useful in understanding the changed potential for H_2S generation in the sewage and its transfer into the sewer gas space under different design and operating conditions, and the consequent change in odour and corrosion risks. Models are often used to identify potential risk areas in a network as well as assessing the effectiveness and viability of O&C mitigation options, e.g., chemical dosing, forced ventilation and treatment.

In addressing the potential impact of climate change, the input data to the models will need to be updated periodically to reflect the current view of the climate change path and the variables that influence the asset lives (due to corrosion) or odours. Note that there will be a need to update the contemporary models to reflect the recent phenomena of water corporations replacing corrodible materials with non-corrodible materials to increase asset lives, resulting in odours in large part being transferred downstream and with increased odour emissions risk. This indirect effect partly or indirectly driven by climate change will require additional air treatment facilities at more locations throughout a sewerage system.

The model types range from MS Excel spreadsheets which use simplified calculations to estimate sulphide generation in pressure and gravity mains, to complex proprietary, dynamic models, which predict spatial and temporal variations of H_2S and other compounds. The choice of which model to use will depend on the objective of the assessment, the quality and extent of the input data, and the proposed end use of the output data.

The more common models are detailed in Table 31.

Table 31: Sulphide modelling tools

Model	Description
Spreadsheet tools	Based on empirical relationships (e.g., those developed by Pomeroy and Pankhurst 1977) to estimate sulphide generation in pressure mains and gravity mains. Typically developed 'in house' by water utility companies and consultant groups. Simple and quick to use. Key inputs are hydraulic residence times, sewage biological oxygen demand (BOD), sulphate and temperature. Suitable for high level assessment or as 'screening' tool to assist in identifying risk areas. Do not account for losses of sulphide to the gas phase. Does not predict the effect of H_2S control strategies.
Interceptor (CH2M HILL)	Predicts the generation, transport and fate of H_2S in sewers using a steady-state mass balance approach. Often used in conjunction with the Sewer Corrosion and Odour Research (SCORe) ventilation tool. Proprietary model, now superseded by the more advanced WATS and SeweX models (see below).
Toxchem (Hydromantis)	Used primarily to predict volatile organic compounds and hazardous air pollutant emissions from wastewater treatment plants. Developed to overcome limitations of Water9 (USEPA) package (see Note 1). Based on mass balance of several compounds in WWTPs for each unit operation. Commercially available software package.
WATS and MegaVent	Complex model, with multiple sewage quality inputs. Requires outputs from GIS and hydraulic modelling. Describes anaerobic and aerobic processes for the estimation of sulphide in liquid and gas phase in sewage transport systems. Includes sewer ventilation module for the prediction of changes to H_2S gas concentrations and corrosion rates in sewers with different ventilation parameters. Estimates effect of H_2S control strategies, e.g., chemical dosing, ventilation. Can be expensive to use due to resources in setting up model and analysis. Not available as a commercial software package.

Model	Description
SeweX (University of Queensland)	Complex model, with multiple sewage quality inputs. Requires outputs from GIS and hydraulic modelling. Predicts spatial and temporal variations of various compounds, e.g., sulphide, methane, COD, pH, in sewage transport systems. Estimates effect of H_2S control strategies, e.g., chemical dosing, forced ventilation. Can be expensive to use due to resources in setting up model and analysis. Currently SeweX is a service business of UniQuest Pty Ltd (University of Queensland).

Notes: 1. Water9 model software is outdated and is no longer supported by USEPA.

A.5.8.2 Odour dispersion models

Odour dispersion modelling is typically used to assess the ambient air impact arising from the release of odour (i.e., complex mix of H_2S and other odorous components) to the atmosphere. This can be done for a simple vent stack along a sewer gravity main or for a WWTP site involving several odour emission sources. With projected changes to odour emissions at WWTPs from climate change, e.g., due to an increase in BOD load to a lagoon-based treatment plant, odour dispersion modelling can compare baseline (current) odour risks with future scenarios which incorporate CC parameters. Incorporating CC impacts is not expected to influence the selection of the dispersion model, i.e., the same model used for baseline assessments is suitable for assessing CC impact scenarios.

Typical air dispersion model options include AERMOD, CALPUFF, TAPM and WRF. These take account of temperature effects impacted by climate change.

Rising temperatures may also affect wind conditions and atmospheric stability in some locations. The choice of dispersion model should reflect the local impacts of climate change - this may mean recommending an alternative to models traditionally used by environmental authorities.

The choice of model will depend on the terrain and meteorology at the site (e.g., a Gaussian model will not be suitable for a site with complex meteorology where the use of a 'puff' model would instead be required), and the objective of the modelling (e.g., simple approach required for basic comparison of potential mitigation options). For odour modelling assessments which are required as part of a government approvals process, the respective local jurisdiction guidelines for the selection of model should be followed.

A.5.8.3 Limitations of models

With the use of any model, it is important to understand the sensitivities of the outputs with variable input data. These impacts, along with the inherent uncertainties and limitations associated with mathematical model representations, should be considered.

The frequency of modelling to establish the quantitative impacts and trends of climate change variables should be linked to:

- the types of planning (strategic, tactical, operational level);
- operational and decision-making timeframes and the timing; and
- variability and rate of climate change impacts themselves.

A.6 Consideration of Climate Change in Asset Management Planning Cycles

Figure 31 shows an example of a high-level generic asset management decision process (appropriate for taking account of climate change impacts). It highlights additional steps to consider for the expected impacts of climate change, which should be considered as part of best practice in asset management planning.

The following describes the additional factors relating to climate change in each of the stages.

1. Recognising and understanding issues

To understand the relevant threats relating to climate change consider the asset, business and regional issues (i.e., climate hazard conditions specific to that region) on a case-by-case basis. The climate projections for Victoria are described in Section 3 of this guideline. Different regions in Victoria are expected to face different vulnerabilities. For example, a sewer pipeline will be vulnerable to different impacts if it is in a coastal area compared to inland; or a high flow catchment area, compared to a dry area.

Climate change may affect failure modes, mechanisms, and causes. A risk assessment to determine consequence and likelihood of applicable climate change factors on the failures should be carried out.

The assessment should consider the impact of climate change on the risk of physical failure of an asset, i.e., one component of the system, as well as the risk of failure to deliver the various service and other obligations (associated with and dependent on wastewater system assets).

The Climate Change Adaptation and the Australian Urban Water Industry could be used when examining possible causes of future asset failure (WSAA, 2012) This document considers the following:

- How can and how do the assets fail? (Refer to Step 2 - Analyse Impacts)
- What are the likelihood and consequences of asset failure? (Refer to Step 3 – severity and likelihood of failure and implications for asset life and risk)
- What are the financial, social, and environmental consequences of asset failure and repair? (Refer to Step 4 – Develop appropriate response strategies)
- What are the systems in place to prevent or mitigate failure? (Refer to Step 5 – Business case for maintenance, rehabilitation, and renewals

2. Analyse impacts

Climate change may affect assets to a varying extent. The impacts should be assessed for a range of climate projections based on the asset location, design stress and physical stress on the materials. The analysis should also consider how compounding factors may affect actual asset life. The impact assessment should be undertaken quantitatively as far as possible.

To a limited extend, records of past asset failures can be used as an indication of potential future failures. Monitoring types and causes of asset failure may show trends in changing conditions and stress on assets. This should be considered alongside future climate projections. Research about causes of failure for specific asset classes should also be undertaken where possible.

A form of Failure Modes Effects and Criticality Analysis (FMECA) analysis or equivalent should underpin the impact assessment.

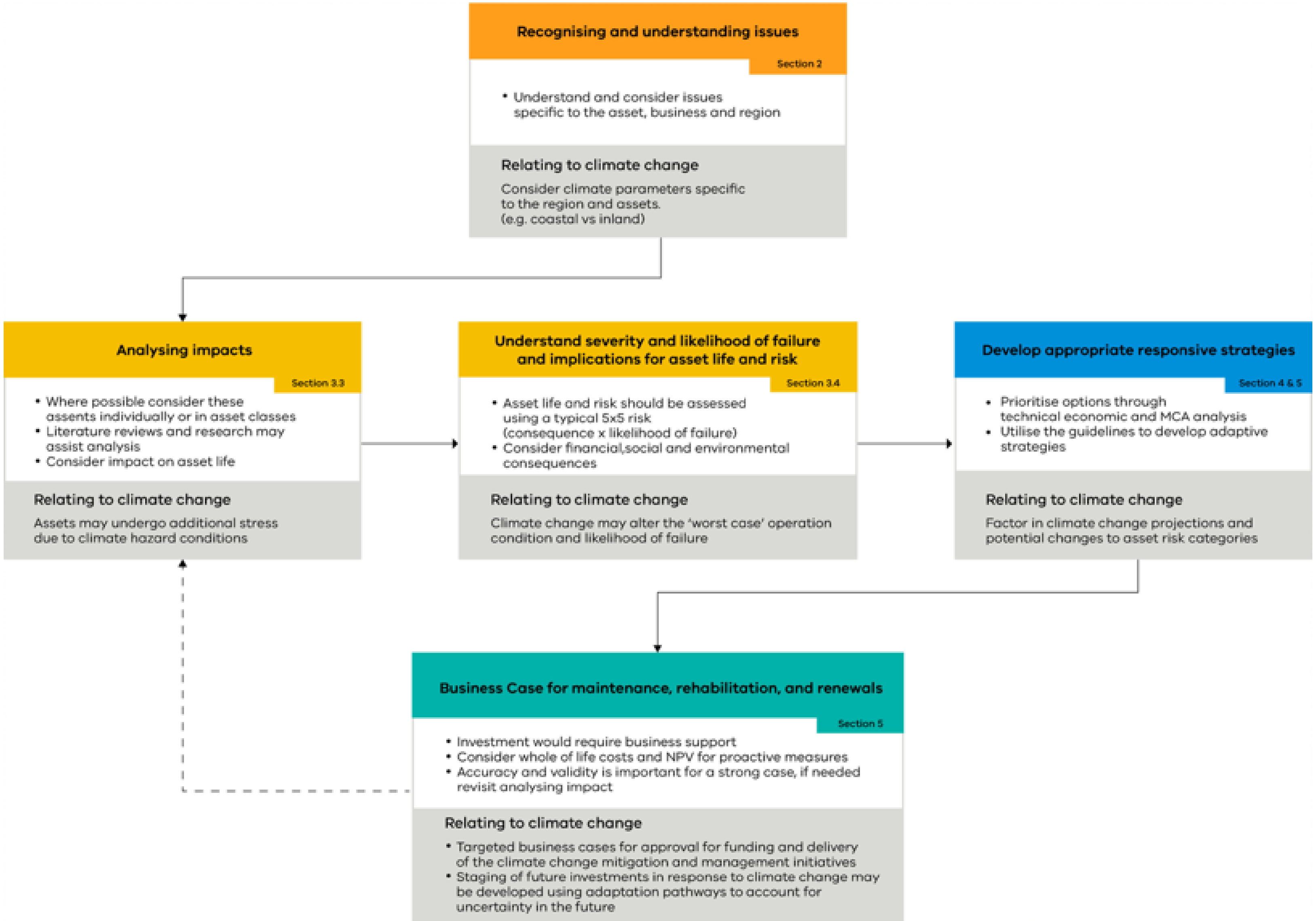


Figure 31: Example asset management decision framework (taking account of climate change impacts)

3. Understanding severity and likelihood of failure and implications for asset life and risk

From the impact analysis, the impact of climate change on the severity of failure should be considered. For example, with a projection of more intense rainfalls, a failure of a sewer could cause an increase in overflow volume and flooding during extreme rain events. This could increase the severity in the asset risk process and may require additional measures to mitigate. Impacts could vary between asset types and locations (e.g., coastal areas will have salt exposure).

This process would involve working with a typical 5 x 5 (consequence x likelihood of failure) matrix, which is forward looking, reflecting the future impacts of the relevant climate change factors. Water corporations will need the ability to assess their own assets within an equivalent matrix.

Both, the implications for asset life and the risk to service obligations from the asset risk (consequence of failure x likelihood of failure) should be understood and assessed. The information should be used to inform risk-based decision making of climate change impacts. The likelihood (e.g., failure to achieve a service or tactical objective under climate change) and consequences (the extent and severity of the impacts if failure was to occur) and risk (the combination of the two) of a failure event occurring need to be assessed separately.

The risk rating of an asset can be affected by the review of the consequence and likelihood of failure. Ultimately this could be key in reviewing maintenance, rehabilitation, and renewals projects for existing assets and drive updates in management strategies.

Climate change may alter the likelihood, but potentially less so (or in some instances not at all) the consequence of failure. For example, extreme storm events may potentially occur more frequently due to climate change, but the resulting consequence or impact on the system or infrastructure could be the same each time the storm event occurs. There are some exceptions, for example, the receiving environment into which sewer spills are discharged can already be under stress due to other impacts from climate change, exacerbating the environmental consequences of the discharge. An assessment of both, the extent of the impacts (e.g., are they more widespread affecting more people or assets) and their severity (e.g., flooding of assets to a greater depth) should occur.

Given the potential for increases in stress on assets, how climate change factors could change vulnerability to failure (both structural and service) should be considered. If it is shown to decrease asset life, the asset degradation curves would need to be adjusted when used to predict residual asset life.

4. Develop appropriate response strategies

Options analysis (technical, economic, MCA) should be used to identify the appropriate (effective and efficient) ways to , , address the impacts on assets from climate change. Response strategies can be in the form of tactical plans and operational initiatives. They can involve a mix of operations, maintenance, works (infrastructure – rehabilitation, renewals, new; equipment) or policy initiatives. Response strategies may be framed around a series of adaptation pathways, focused on options analysis at progressive planning stages.

Asset management strategies for existing and new assets should factor in climate change projections. For existing assets, previous reviews may not have adequately considered this.

Current asset management strategies, asset management plans and specific components of those (e.g., renewals, rehabilitation, upgrades, and proactive and reactive maintenance plans) and programs of work with a 5-to-20-year outlook may require revision. Assets may move from one risk category to another when climate change impacts are considered (e.g., ‘high’ to ‘very high’ or ‘extreme’). An existing sewer already vulnerable to fluctuating underground moisture levels may fail earlier than expected due to additional material strain. Standing maintenance interventions may need to be brought forward or adapted to incorporate this additional risk.

For new assets, there is greater opportunity and flexibility to plan and implement asset management strategies. Best practice would be to have a staged and adaptive management strategy with provision for planned maintenance, rehabilitation, and renewals as appropriate early in the design phase. Strategic preventative maintenance strategies with proactive measures should be decided in advance. Therefore, when limits or trigger points (linked with individual climate change factors and identified as part of an adaptive pathways planning approach) are reached, appropriate action can be taken.

The asset management plan should be developed using the approaches provided in Section 5, 6 and 7 of the Guidelines to ensure it is adaptive, keeping as many responses available as possible to manage uncertainty in projections and impact in the future.

5. Business case for maintenance, rehabilitation, and renewals

Any decisions or investments to manage or mitigate the impacts of climate change could require development of a business case. The response strategies above can be used to prepare a business case for approval for funding and delivery of the climate change mitigation and management initiatives. The business case should consider the whole life costs and NPV for proactive measures. Staging of future investments in response to climate change could be developed using adaptation pathways to include provisions for uncertainty in the future as outlined in Section 5, 6 and 7 of the Guidelines. Accuracy and validity are important for a strong case. Revisions or updates to the impact analysis may be required to ensure this.

The business case should explicitly reflect the water corporation's declared risk appetite for new infrastructure and upgrades to existing infrastructure.

A.7 Example approach to assessing environmental and health issues under the GED framework

The GED requires demonstration (through data and analysis) that the measures in place to prevent failure and manage the consequences of potential spills to the environment take account of climate change effects. The measures and interventions need to be costed and a reasonable position adopted which provides an appropriate balance weighing those costs against the residual risk of environmental harm (after implementing the proposed measures and interventions).

Compliance with the GED about the impacts of climate change typically includes:

- Understanding of the risks and their consequences
- Controls, management practices and monitoring in place to minimise these at present

Plans and commitments to implement upgrades and improvements where these are necessary to meet SFARP (including appropriate timeframes which may vary depending on level of risk and cost of minimisation measures)

An example approach to assessing risks to human health and the environment under a GED framework the spills risk from a typical sewage pump station (SPS) with the potential to overflow to a nearby waterway or marine environment is indicated in Figure 32 below. This bowtie approach considers both:

- the likelihood of failure of each individual component in the pump station, plus credible combinations of failure events are shown on the left-hand side of the Bowtie. Existing and proposed controls designed to prevent such a failure are also listed.
- the consequences of the failure occurring is shown on the right-hand side of the Bowtie, including a summary of the environmental (or other) aspects which may be impacted. Existing and proposed controls designed to mitigate the impacts, if the failure event occurs, are also identified.

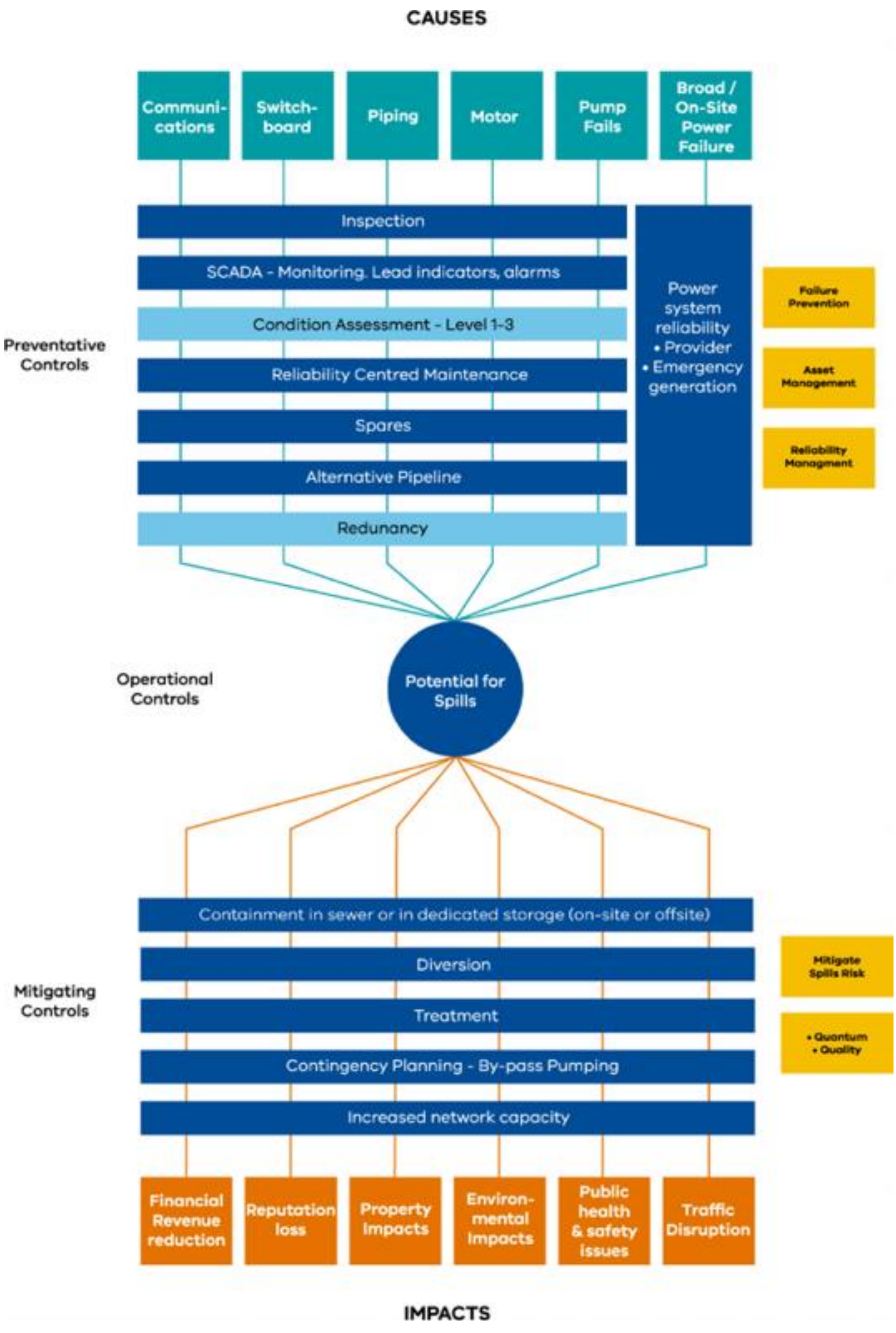


Figure 32: GED framework of the spills risk from a typical sewage pump station (SPS) with the potential to overflow to a nearby waterway or marine environment

The likelihood of failure of individual components will need to consider the effects of climate change (e.g., increased temperatures, increasing failure rate of switchboards, temperature effects on the reliability of the incoming power supply and/or of standby generator reliability etc). Appropriate maintenance regimes, spare equipment and parts and effective contingency plans with proven response times are also relevant factors to consider in managing the likelihood of failure.

The consequences of failure can be mitigated by providing sufficient on-site and/or upstream storage and/or sewer diversions to prevent spills when SPS failure occurs. The amount of storage required will depend on the flow patterns and changes to PDWF (peak dry weather flow) and wet weather flow (WWF) peaks as impacted by climate change.

A.8 Further Resources for Reducing GHG and Energy Use

The purpose of this Appendix is to identify resources available to assess GHG emissions from relevant wastewater treatment assets for both base case (BAU) conditions and for future climate change conditions under nominated climate scenarios (RCP8.5, RCP4.5).). The assessment of the impacts of these climate change scenarios on plant operating conditions (using a bookend approach) will provide the inputs for assessment procedures referenced. This would enable a comparison of the extent of GHG emissions influenced by climate change with the base case and identification of mitigation responses and their timing.

Wastewater treatment systems contribute to GHG emissions through:

- Direct emissions from sources owned by water corporations, wastewater treatment systems typically emit methane, nitrous oxide and carbon dioxide from treatment processes and fuel usage (noting direct emissions of carbon dioxide from treatment systems are considered biogenic and not included in Scope 1 emissions reporting).
- Indirect emissions that arise from the production of energy used by water corporations.
- All other indirect emissions from purchased materials, fuels or services.

Refer to Figure 33 for a summary of sources of Methane and N2O emissions.

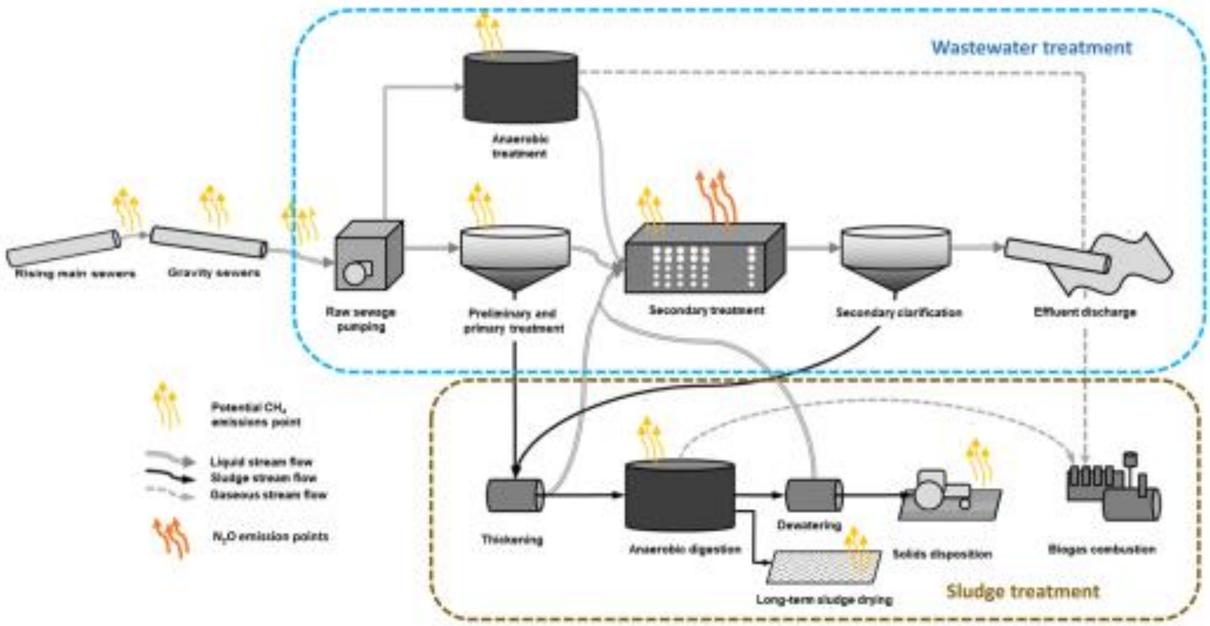


Figure 33: Sources of N2O and CH4 emission points from wastewater transport and treatment (Ren & Pagilla, 2022)

A roadmap to reducing the carbon footprint in the water cycle is outlined in the recent IWA Water Sector Decarbonisation, Carbon Capture and Utilization book (Ren & Pagilla, 2022), and includes:

1) Conserve water to reduce the energy needed throughout the water cycle.
2) Reduce water loss (distribution) and infiltration (collection) to reduce the flows (and in some cases loads) to be treated.
3) Maximise energy generation. Generate energy by converting the organics in the wastewater to fuel, heat or electricity. Install solar or wind turbines for renewable energy generation.
4) Be energy efficient. Energy efficient processes and equipment can be selected.
5) Maintain equipment. Good housekeeping, good maintenance, and operating facilities as they are keys to ensuring a plant operates well which will keep direct and indirect carbon emissions lower.

Additional steps being taken by some Water Authorities include the following:

- Increase their energy generation through the importation of additional organic waste for digestion to produce biogas.
- Reduction in fugitive Methane (CH_4) and Nitrous Oxide (N_2O) emissions.

The following resources may assist in determining opportunities to reduce energy usage and GHG emissions for a wastewater system:

- Pathways to Water Sector Decarbonization, Carbon Capture and Utilization
  Pathways to Water Sector Decarbonization, Carbon Capture and Utilization | eBooks Gateway | IWA Publishing (iwaponline.com)
- NSW Office of Environment & Heritage, Energy Efficiency Opportunities in Wastewater Treatment Facilities
  https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Energy-savings-and-resource-efficiency/wastewater-treatment-facilities-energy-efficiency-opportunities-190114.pdf
- Benchmarking energy use for wastewater treatment plants (D de Haas et al., Water e-Journal Vol 3 No 1 2018)
  https://www.awa.asn.au/resources/latest-news/business/assets-and-operations/benchmarking-energy-use-for-wastewater-treatment-plants
- Energy Efficiency Benchmarking Wastewater Treatment Plants and Sub-Metering Guidance (WSAA, 2017) (A copy of the report is available to WSAA members)
- Quantification and Modelling of Fugitive Greenhouse Gas Emissions from Urban Water Systems:
  https://iwaponline.com/ebooks/book/844/Quantification-and-Modelling-of-Fugitive
- Further information on reducing fugitive methane emissions is found in the EvEmBi project (Evaluation and reduction of methane emissions from different European biogas plant concepts):
  https://www.europeanbiogas.eu/project/evembi/
- Overhauling the greenhouse gas emissions accounting guidelines for wastewater handling (Utility Magazine, 6 August 2019), by Professor Zhiguo Yuan AM, Director, Advanced Water Management Centre, The University of Queensland and Dr David De Haas, GHD
- https://utilitymagazine.com.au/overhauling-the-greenhouse-gas-emissions-accounting-guidelines-for-wastewater-handling/
- Better Understanding Wastewater Treatment's Nitrous Oxide Emissions (The case for revised reporting protocols using variable emission factors based on nitrogen removal):
  https://www.awa.asn.au/water-e-journal/water-e-journal-better-understanding-wastewater-treatments-nitrous-oxide-emissions
- A method to estimate the direct nitrous oxide emissions of municipal wastewater treatment plants based on the degree of nitrogen removal (T. Valkova et al., Journal of Environmental Management 279 (2021) 111563)
  https://www.sciencedirect.com/science/article/pii/S0301479720314882
- Estimating emissions and energy from wastewater handling (domestic and commercial) and (industrial) guideline (Clean Energy Regulator, Updated July 2021)
  http://www.cleanenergyregulator.gov.au/DocumentAssets/Documents/Estimating%20emissions%20and%20energy%20from%20wastewater%20handling%20guideline.pdf
- Insights into Nitrous Oxide Mitigation Strategies in Wastewater Treatment and Challenges for Wider Implementation (Duan et al. Environ. Sci. Technol. 2021, 55, 11, 7208–7224)
- Climate Action in the Water Industry – Embracing the Challenges of N2O:
  https://www.jacobs.com/newsroom/news/climate-action-water-industry-embracing-challenges-n2o
- Sludge-Drying Lagoons: A Potential Significant Methane Source in Wastewater Treatment Plants (Y. Pan et al., Environ. Sci. Technol. 2016, 50, 3, 1368–1375)
- ANZBP Biosolids Carbon Climate Discussion Paper (ANZBP, 2012)
- Water Services Association of Australia: Fugitive Emissions from Sludge Lagoons Technical Paper – NGER Determination submission (April 2014)
- UK Water Net-zero Carbon: Quantifying the Benefits of Biosolids to Land:
  https://www.jacobs.com/newsroom/news/uk-water-net-zero-carbon-quantifying-benefits-biosolids-land

Whilst the resources provide a range of valuable information to assist in assessing and reducing energy usage and GHG emissions, it is important to note the following:

- The basis for some of the assessments are very site specific and not always transferable to another site, therefore care should be taken by the reader to consider their specific infrastructure and operations,
- N_2O is a potent GHG gas with a global warming potential of 265 CO_2-equivalents. N_2O emissions are generated by nitrification and denitrification processed used to remove nitrogenous compounds from wastewater. There is on-going significant global research into its production and emission. The current National Greenhouse and Energy Reporting methodology estimates N_2O emissions from wastewater treatment plants based on an Emission Factor (EF) multiplied by the % Total Nitrogen (TN) removed, and an EF based on the discharge location for the treated effluent. Recent research has identified that an EF based on the % TN removed may be more representative, with a lower EF for a higher % TN removed, e.g., De Hass et al, Valkova et al. Therefore, care should be taken when assessing N_2O reduction opportunities based on N_2O emissions estimates developed using the NGERs methodology. As illustrated in the resources below, practical reductions in N_2O emissions can be achieved through on-site monitoring and process changes to reduce emissions.
- They are a small sample of the many resources available.

A.9 Melbourne Water Case Study – An example of modelling climate change for sewer network using time series approach

A.9.1 Case study overview

The following provides a more detailed illustration and guidance for application of the time series approach (Approach B, Figure 12) in Section 4 of the Guidelines. This is illustrated based on the information in Table 10.

CASE STUDY	
Wastewater network modelling – for climate change impacts (Melbourne Water)	
What:	A climate change scenario was modelled (with time series rainfall), considering a number of impacts including: • the increase in rainfall intensity which increases inflows to sewers • the increased evaporation and reduced annual rainfall which results in a drier catchment and can reduce the inflows to sewers in some cases and • sea level rise with potential to submerge Emergency Relief Structures (ERS) outlet. The results can be compared against the time series rainfall (without climate change) scenario to understand the sensitivity to climate impacts. Figure 34: describes the steps to develop the inputs to Melbourne Water's hydraulic model for this approach and shows their alignment with the generalised framework outlined in Figure 12. Table 32 provides an overview of key potential climate change impacts on wastewater network hydraulic performance as addressed by Melbourne Water.
Challenges:	• Confirm inflow and infiltration peaks and daily flows
Climate change considerations:	Key findings are: • Investigation of the return period of spills indicates that the climate change scenario causes an increase in spill frequency at most locations. • The reduction in inflow / infiltration resulting in a drier catchment is not sufficient to offset the impact of the increased storm intensity mainly due to the continued inflow from illegal connections. • Sea level rise causing ERS submergence may increase spills in the network upstream. Also considers: • The time series impact on STPs over weeks/months (rather than 30 min intervals for the network). • The influence of operational responses and decisions made in the months prior informed by weather outlook • Make whole sewerage system and whole water cycle decisions (i.e., integrated water management)

Table 32: Overview of key potential climate change impacts

Potential climate hazard conditions	Potential impact on sewer network	How addressed in modelling	Reference
Storms become more extreme	Wet weather inflows increase.	50-year time series of data adjusted so that intensity of larger storms is increased.	Figure 34: Appendix A.9.2 Guidance notes 1 to 4

Potential climate hazard conditions	Potential impact on sewer network	How addressed in modelling	Reference
Annual rainfall totals reduce	The catchment becomes drier on average, so when a storm does occur runoff may reduce.	50-year time series of data adjusted so that smaller storms are reduced. The overall annual rainfall totals are reduced. This reduces the antecedent wetness and hence runoff.	Figure 34: Appendix A.9.2 Guidance notes 1 to 4
Evaporation increases	The catchment becomes drier on average, so when a storm does occur runoff may reduce.	The evaporation used as an input to the modelling is increased. This reduces the antecedent wetness and hence runoff.	Appendix A.9.2 Guidance note 3
Sea / flood level rise	Low lying ERS outlet submergence increases. This could change the distribution of spills from ERS to manholes.	Sea / flood levels adjusted when applying boundary conditions for ERS.	Appendix A.9.2 Guidance note 4

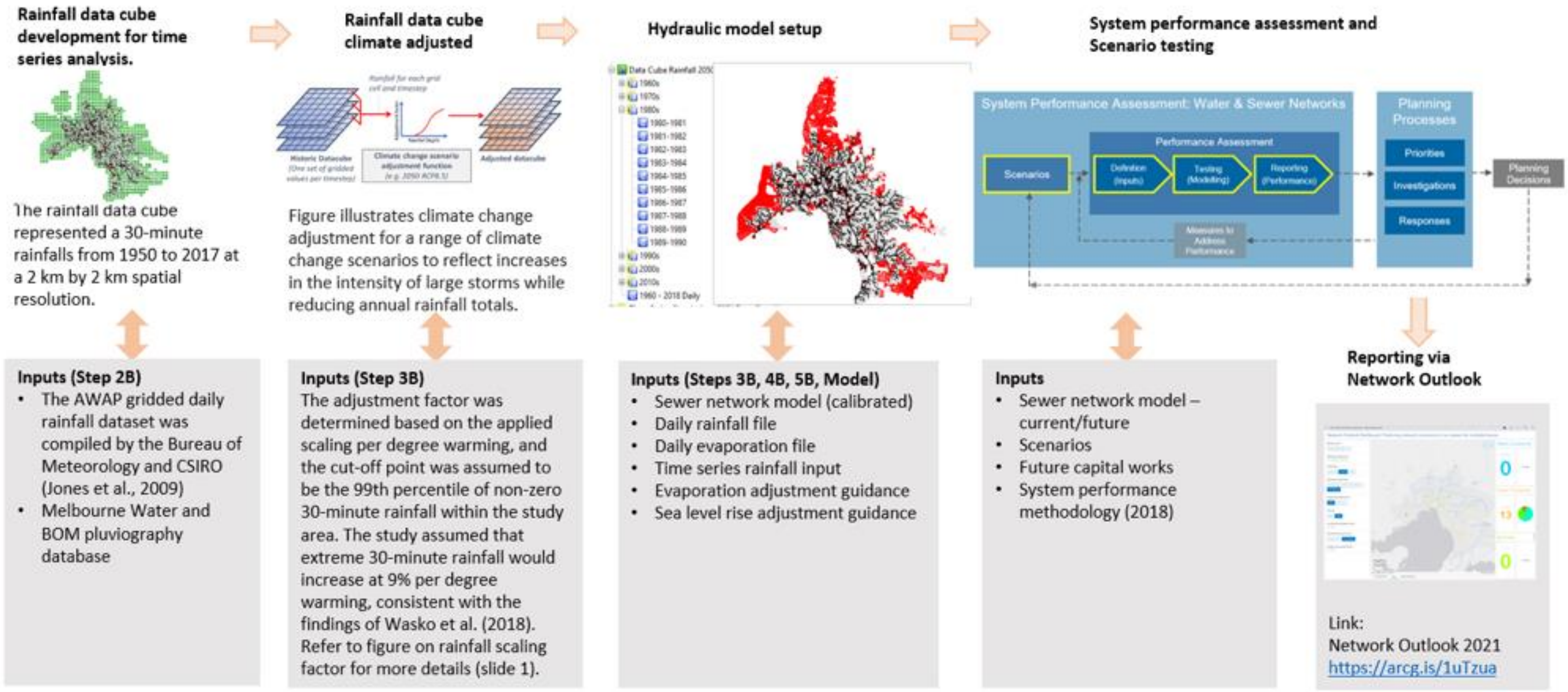


Figure 34: Melbourne Water Case Study: More detailed specific illustration of Melbourne Water's time series approach aligned with the general framework for sewer network analysis of climate change effects on spills (DWF, WWF) and transfer capacity (Jones et al 2009 and Wasko et al. 2018)

A.9.2 Guidance Notes

Guidance notes below provide additional information used to inform the case study including development of the model inputs to address potential impacts of climate change.

1. Climate change scaling factors

The climate change scaling factor applied to the rainfall data cube for various future horizons was taken from ARR data hub (HARC, 2019), as shown in the Figure 35: below.

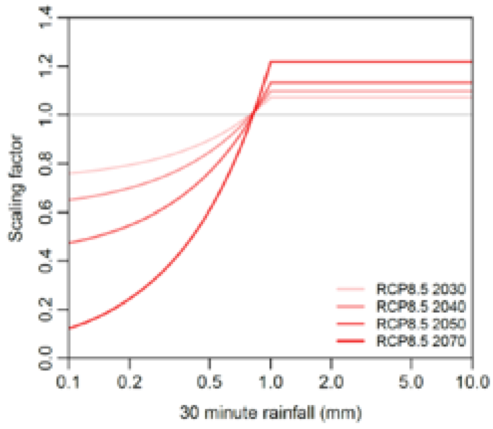


Figure 35: ARR data hub climate change scaling factor

2. Sub-daily rainfall – climate change adjustment methodology

Some guidance in preparing the sub-daily rainfall scale to model Melbourne Water's wastewater network under projected climate change can be derived from the Water Availability Guidelines (DELWP, 2020) for

- Changes to peak rainfall (see Section 5.9.4)
- For peak sub-daily rainfall, e.g., peak 30-minute rainfall (see Section 5.9.4)
- Supplementary guidance on sub-hourly rainfall (see Appendix B.7)
- Additional reference, "Representing climate change projections in rainfall, evaporation and sea level inputs to hydraulic models of Melbourne's sewer network, HARC for Melbourne Water 2019*"* (HARC, 2019)

3. Adjusting pan evaporation for climate change

Guidance on projected percentage changes in the evaporation inputs to Melbourne Water's Infoworks model was derived for the applicable Natural Resource Management cluster from "Climate Change in Australia - Information for Australia's Natural Resource Management Regions: Technical Report, CSIRO and Bureau of Meteorology, Australia, 2015".

Recommended percentage increases in pan evaporation were determined for the warm season (November-April) and cool season (May-October) respectively, for each projection year.

Projected changes in mean cool season, warm season and annual potential evapotranspiration (PET) increase between 2030 and 2050. From 2050 to 2070, changes in warm season and annual PET are both projected to stabilise, with mean cool season PET projected to increase. Mean annual PET is projected to increase by about 9% from historical climate levels by 2050 and then projected to remain at about 9% to 2070 (Meteorology, 2015)

4. Adjusting sea level rise for climate change

Guidance on adjusting sea level rise for climate change was sourced from:

- Effect of Climate Change on Extreme Sea Levels in the Western Port Region, Impacts of Climate Change on Human Settlements in the Western Port Region: An Integrated Assessment (McInnes K. M., 2008)

- A Modelling Approach for Estimating the Frequency of Sea Level Extremes and the Impact of Climate Change in Southeast Australia (McInnes K. M., 2009)

McInnes et al. (2008, 2009) made an overall assessment of the storm tide levels in Port Phillip Bay under historical climate conditions and for 2030 and 2070 climate change projections. This work drew upon joint probability and frequency analysis of historical storm tide data, along with hydrodynamic modelling of Bass Strait and Port Phillip Bay. For the climate change projections, it drew upon the Global Climate Models (GCM) projections released by the IPCC in 2007.

Guidance was provided on projected water levels in Port Phillip Bay, associated with storm surge events under projected future climate change. Under current climate conditions, the 18.1% AEP storm surge level was 0.87 m AHD. This was projected to increase by 0.14 m (to 1.01 m AHD) by 2030 and to increase by 0.44 m (to 1.31 m AHD) by 2070 under the RCP8.5 scenario.

5. Selection of significant rainfall events

The selection of rainfall events considered to be hydraulically significant is important. For the Melbourne Water specific example an “event” was identified where the rolling 2-day average was 20 mm or greater (again Melbourne Water transfer network specific). A total of 325 events were identified across the 50-year time period.

Further refinement of the events selected for the model simulation (to 94 events) was done based on historical spills, flow events critical to wastewater treatments plants as well as identifying all events that will likely to create a spill in the network.

Individual water corporations may choose a different way to select or consider such events or issues, including production of output information for downstream assessment purposes, e.g., by using continuous simulations rather than discrete events.

A.10 Example of how the Guidelines could be applied – climate hazard condition consideration in treated wastewater reuse planning

A hypothetical case study was prepared to provide an example of how the Guidelines could be applied to assess the impacts of climate change on a component of the wastewater system.

The case study is located within central Victoria and considers the impacts of climate change on a treated wastewater winter storage and recycled water irrigation demand. The case study uses the structure presented in Figure 5.

A.10.1 Step 1a

> Are the external and internal drivers for consideration of climate change understood? Have they changed or are they likely to change?

The drivers are to assure continued reliance on treated effluent reuse via a combination of land irrigation to contracted customers and adequate winter storage to avoid disposal to local watercourses and associated environmental constraints. In this example, the external and internal drivers were understood in the context of climate change and were considered unlikely to change. The drivers are to assure continued reliance on reuse/disposal of treated effluent via a combination of land irrigation to contracted customers and adequate winter storage to avoid disposal to local watercourses and associated environmental constraints.

A.10.2 Step 2a

> What component/s of the wastewater system are being considered?

The system included in the hypothetical case study comprises of a treated wastewater winter storage and recycled water irrigation system, refer to Figure 36. The system includes the physical infrastructures required to store, transfer and reuse the recycled water including the power supply to the transfer system, required land for storage and irrigation, and the receiving waterway for potential spills of recycled water.

A.10.3 Step 2b

> What climate hazard conditions may impact the wastewater system?

Using the information provided in Appendix A.1.1 the winter storage and irrigation system could be impacted by the following climate change conditions and hazards:

- larger heavy rainfall events, stormwater and riverine flooding
- drier conditions (reduced rainfall, greater evaporation), more severe droughts and
- more severe bushfire weather.

A.10.4 Step 3

> Review service obligations and objectives

Using the example objectives in Table 8, hypothetical objectives were developed for this example (see Figure 35).

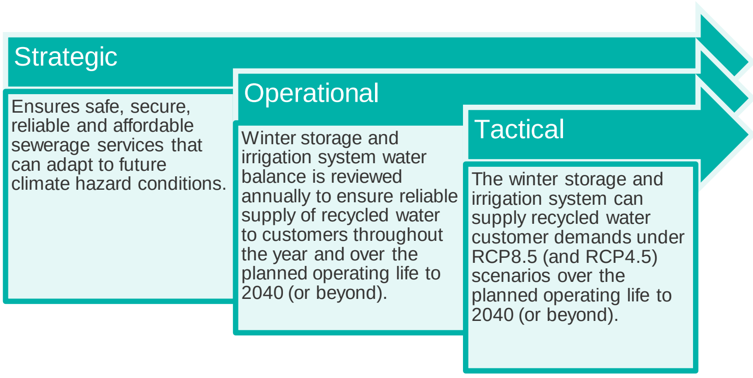


Figure 36: Example objectives for climate changes impacts on a wastewater plant

A.10.5 Step 4

Will climate hazard conditions hinder achievement of objectives?

Using the climate hazard conditions identified above, the simplified scanning approach (refer Section 3.2.1) was used to consider the winter storage and irrigation system (see Table 33).

Table 33: Climate change impacts scanning approach outcome

	Climate Hazard Conditions							
Winter storage and irrigation system	**Heavy rainfall**	**Temperature: extreme**	**Drier Climate**	**Sea Level Rise**	**Bushfire weather**	**Carbon dioxide**	**Relative Humidity**	**Wind speed**
Will the climate hazard condition hinder the system's ability to achieve objectives identified								

The winter storage and irrigation system could be directly influenced by heavy rainfall and a drier climate. If a drier climate occurs, the system may not be able to meet recycled water customer demands, hindering the water corporation's ability to meet the above objectives. Therefore, this climate hazard condition was considered to have a high impact on the system.

Heavy rainfall could result in storm events which may cause spills from the winter storage. Although this should be considered when planning and designing winter storage and irrigation systems to adapt to climate change, this would not influence the water corporation's ability to achieve the hypothetical objectives identified in Figure 36. Therefore, this climate hazard condition was considered to have a medium impact for this example.

Bushfire prone areas and bushfire management overlay mapping were obtained from www.data.vic.gov.au. A review of mapping for bushfire prone areas and bushfire management overlays confirmed that the system used in this example is located within a bushfire prone area, but not within a bushfire management overlay (which has a higher bushfire risk). On this basis bushfires were considered to have a medium impact.

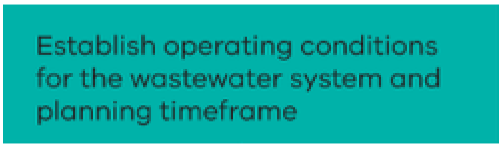
The example system is not adjacent to the ocean. Therefore, sea level was considered to have a low impact on the system.

Carbon dioxide, relative humidity and wind speed should also have a low impact as these climate hazard conditions typically do not influence the operation or design of this system.

Temperature extremes may impact power supply to the irrigation system pumps, but this was considered to have a low overall impact on the system. Temperature is linked to evaporation which was considered to be accounted for in the drier climate hazard condition.

For the purpose of this example, an impact assessment included climate hazard conditions with a potentially high impact on the system. Therefore, only the impacts of the drier climate on the treated wastewater winter storage and recycled water irrigation demand were considered.

A.10.6 Step 5



The operating boundary conditions for the treated wastewater winter storage and recycled water irrigation system are shown in Figure 36.

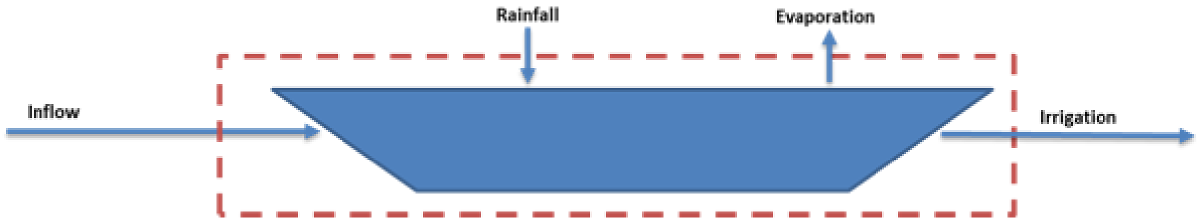
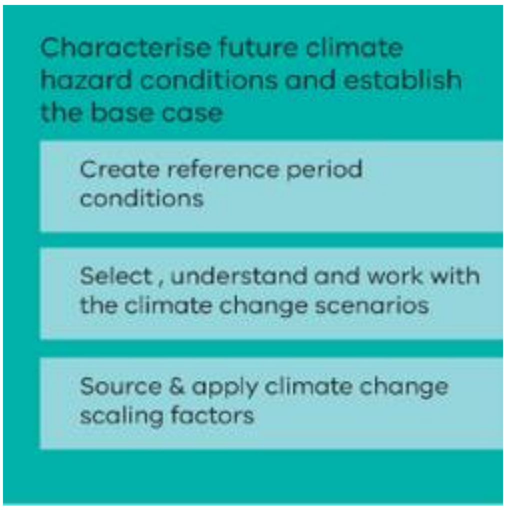


Figure 37: Winter Storage Water Balance

A drier climate would predominately impact the winter storage rainfall and evaporation rates and the irrigation demand. Rainfall and evaporation are the key climate variables that would influence these boundary conditions. The winter storage inflow is typically from the upstream wastewater treatment plant. A drier climate could result in water restriction and a reduction in stormwater infiltration reducing the wastewater treatment plant inflows and increasing the loads. It is assumed that these impacts would be managed by the wastewater treatment plant process. Therefore, the winter storage inflows used to inform the hypothetical case study already account for these impacts.

The planning timeframe depends on data availability, planned asset life and/or planning timeframe, refer Appendix A.4.1. The hypothetical case study used a planning timeframe of 2040 based on an assumed 20-year planning cycle and a clay lined winter storage lagoon with a typical 20-year design life.

A.10.7 Step 6



A.10.7.1 Create reference period conditions

Consistent with the Water Availability Guidelines, a reference period of post-1975 was selected, refer Appendix A.4.2.

As identified in Step 5 historic data for rainfall and evaporation was required to inform the hypothetical case study. Using the recommended source in Table 31, daily historic rainfall and evaporation data was obtained from the Bureau of Meteorology between 1 January 1976 to 31 December 2021.

A.10.7.2 Select climate change scenarios

Consistent with the Water Availability Guidelines, the example considered both RCPs 8.5 and 4.5 to provide plausible ranges in future climate conditions. The main focus of the case study is on RCP8.5, as it provides the most extreme conditions and effectively the worst-case scenario.

A.10.7.3 Source and Apply Climate Change Scaling Factors

Using the information provided in Appendix A.4.3, the Victorian Climate Projections 2019 (VCP19) were used as the data source for the climate change scaling factors. The example is located in central Victoria. Therefore, the Goulburn Region Project Change Summary spreadsheet was used.

The example required climate change factors for rainfall and evaporation. The high-resolution results were used, as they are based on a 5km-resolution downscaled model output that draws on AR5 climate models and emission scenario. This data has a smaller spatial scale that is more reflective of the local topographic conditions.

The 2050 climate factors were selected as the closest values to the 2040 planning timeframe. The climate change factors used for the case study are shown in Table 34.

Table 34: Victorian Climate Projections 2019: High-resolution (CCAM) results

Variable	Unit	RCP	2050 RCP4.5			2050 RCP8.5		
			Median	Lower	Upper	Median	Lower	Upper
Precipitation	%	Annual	-5%	-18%	3%	-14%	-21%	2%
Precipitation	%	Summer	3%	-3%	18%	-3%	-5%	2%
Precipitation	%	Autumn	-3%	-22%	38%	-10%	-22%	6%
Precipitation	%	Winter	-10%	-15%	3%	-16%	-24%	-4%
Precipitation	%	Spring	-12%	-38%	-3%	-22%	-28%	12%
Pan evaporation	%	Annual	18%	6%	22%	25%	10%	32%
Pan evaporation	%	Summer	24%	9%	40%	35%	16%	57%
Pan evaporation	%	Autumn	11%	1%	19%	18%	7%	20%
Pan evaporation	%	Winter	3%	1%	5%	5%	3%	6%
Pan evaporation	%	Spring	28%	13%	40%	39%	15%	48%

The lower, median and upper climate factors represent the 10, 50 and 90 percentile changes respectively in the regionally averaged annual and seasonal means.

The daily historic rainfall and evaporation data was used to develop monthly historic rainfall and evaporation data between Jan 1976 and Dec 2021. The percentage change values shown in Table 34 were applied to the monthly historic rainfall and precipitation data to determine the projected climate change data.

A.10.8 Step 6

Assess the potential impact of climate change on wastewater systems

A water balance was completed for the system using the historic and climate projected climate data to determine the impact of climate change on the future system.

The water balance was developed on a month-by-month basis using the Guidelines for wastewater irrigation (EPA, 1991) as guidance. 2040 forecast inflows were developed for a hypothetical catchment to inform the water balance.

The winter storage and irrigation system were sized using the 2040 forecast inflows and historic rainfall and evaporation data. The sizing was based on containing and reusing inflows for 90% of the reference years.

As discussed in A.10.6, lower, median and upper rainfall and evaporation climate factors were identified for the case study. Consideration of the median climate factors is generally recommended, as they best represent the climate model outputs. As discussed in Table 28, there is a higher level of confidence evaporation projections then average precipitation projections . Therefore, the case study included a sensitivity analysis using the lower, median and upper rainfall climate factor to provide possible future bookends, see Table 35.

Table 35: Climate conditions used to inform water balance

Climate condition	Changes in the regionally average annual and seasonal means	
	Rainfall	Evaporation
Wet	**Upper (90th percentile)**	**Median (50th percentile)**
Median	**Median (50th percentile)**	**Median (50th percentile)**
Dry	**Lower (10th percentile)**	**Median (50th percentile)**

Both RCP8.5 and RCP4.5 scenarios were considered fixing the winter storage and irrigation sizes based on historic climate data assessment. The comparison of historic versus climate projected rainfall, pan evaporation and spill volumes are shown in Figure 38 for RCP8.5. The projected number of spills over the reference period for both RCP8.5 and RCP4.5 is shown in Table 36.

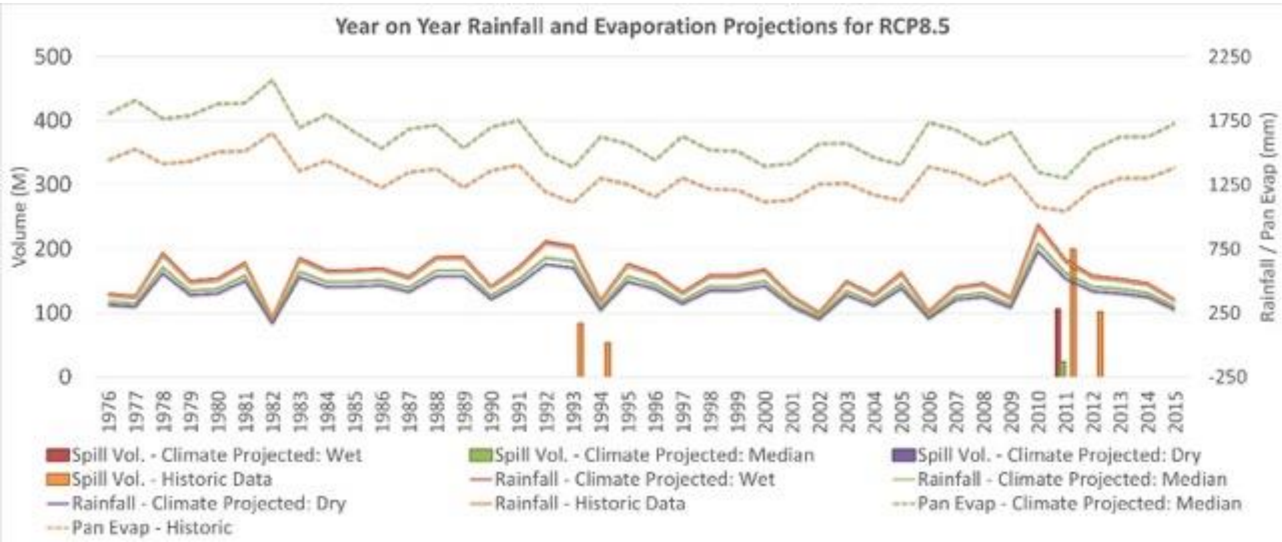


Figure 38: Year on year comparison of historic versus climate projected rainfall, pan evaporation and projected spills for RCP8.5

Table 36: Number of projected spills based on historic, wet, median and dry climate conditions

Description	Historic climate data	Projected climate data					
		RCP4.5			RCP8.5		
		Wet	Median	Dry	Wet	Median	Dry
Precipitation		Upper	Median	Lower	Upper	Median	Lower
Pan evaporation		Median	Median	Median	Median	Median	Median
No annual spills in reference period	4	3	1	1	1	1	0
Number of spills in years where annual rainfall exceeded 90th percentile annual historic rainfall	1	1	0	0	0	0	0

As shown in Figure 38, rainfall and evaporation are projected to decrease and increase respectively. Therefore, available volume in the storage may decrease over time reducing the potential spill volume and number of annual spills. The projected changes are less under the RCP4.5 scenario, resulting in a potentially higher spill volume and frequency than the RCP8.5 scenario.

This means the required winter storage and irrigation system size may be less than projected using the historic climate data. It also means the ability to reliably supply recycled water demands could be affected in the future due to the impacts of climate changes hindering water corporations' abilities to achieve the theoretical objectives identified in Step 3.

The number of months where a recycled water demand shortfall may occur, and the corresponding percentage volume shortfall was assessed for the median climate conditions and RCP8.5 scenario to understand the potential impact of climate change on recycled water reliability, refer to Figure 39. The percentage of months where there is a shortfall in irrigation demand over the reference period for the historic, dry and median climate conditions RCP8.5 and RCP4.5 scenario was also assessed, see Table 37.

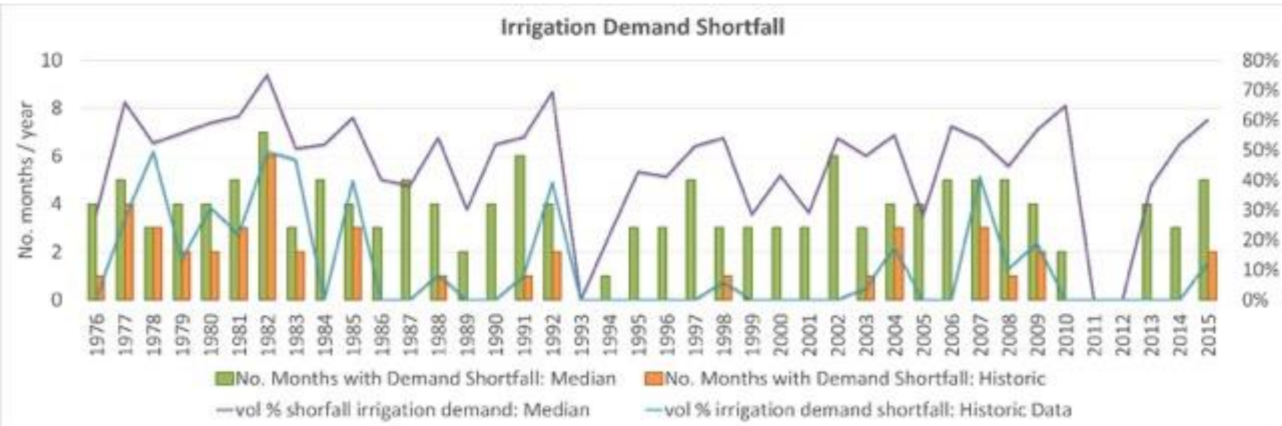


Figure 39: Irrigation demand shortfall historic versus median conditions for RCP8.5 scenario

Table 37: Percentage of months of reference period with irrigation demand shortfall using historic, wet, median and dry climate conditions

Description	Historic Climate Data	Climate Projected Climate Data					
		RCP4.5			RCP8.5		
		Wet	Median	Dry	Wet	Median	Dry
Precipitation		Upper	Median	Lower	Upper	Median	Lower
Pan evaporation		Median	Median	Median	Median	Median	Median
% Months over reference period with irrigation demand shortfall	9%	22%	25%	29%	27%	30%	33%

Figure 39 and Table 37 demonstrate that a shortfall in recycled water demands could potentially increase in the future due to climate change. This could also result in the winter storage being empty for a longer period of time impacting the condition of the lagoon, potentially leading to cracking in the clay liner.

Optimisation of the future required winter storage and irrigation system sizes should be completed further to minimise spill frequency and volume while ensuring an adequate balance to enable the system to reliably supply recycled water demands and achieve the objectives identified above.

A.11 Further references

A.11.1 Victoria's legislation (links downloaded 28 Jun 2022)

Victoria State Government/ DELWP, *Climate Change Act 2017*, https://www.climatechange.vic.gov.au/legislation/climate-change-act-2017

Victoria State Government, *Marine and Coastal Act 2018*, https://content.legislation.vic.gov.au/sites/default/files/2021-06/18-26aa005%20authorised.pdf

Victoria State Government, Water Act 1989, https://content.legislation.vic.gov.au/sites/default/files/2022-03/89-80aa136%20authorised.pdf

Victoria State Government, *Water Industry Act 1994*, https://content.legislation.vic.gov.au/sites/default/files/2021-12/94-121aa076%20authorised.pdf

DELWP, *Statements of Obligations*, https://www.water.vic.gov.au/__data/assets/pdf_file/0015/54330/Statement-of-Obligations-General.pdf

Victoria State Government, *Financial Management Act 1994*, https://content.legislation.vic.gov.au/sites/default/files/77475f8c-7c9d-3bab-b14e-9124ee5b8d61_94-18aa065%20authorised.pdf

Victoria State Government, *Public Administration Act 2004,* https://content.legislation.vic.gov.au/sites/default/files/2021-12/04-108aa081%20authorised.pdf

Victoria State Government, *Environment Protection Act 2017*, https://content.legislation.vic.gov.au/sites/default/files/2021-06/17-51aa005%20authorised.pdf

Environmental Protection Agency (EPA), Environment Protection Regulations 2021 *Environment Reference Standard*, https://www.epa.vic.gov.au/about-epa/laws/epa-tools-and-powers/environment-reference-standard

A.11.2 Victoria's strategies and plans

Victoria State Government/ DELWP, *Water for Victoria – Water Plan,* 2016, https://www.water.vic.gov.au/__data/assets/pdf_file/0030/58827/Water-Plan-strategy2.pdf

Victoria State Government/ DEWLP, *Marine and Coastal Policy,* 2020, https://www.marineandcoasts.vic.gov.au/__data/assets/pdf_file/0027/456534/Marine-and-Coastal-Policy_Full.pdf

Victoria State Government/ DELWP, *Victoria's Climate Change Strategy*, 2021, https://www.climatechange.vic.gov.au/__data/assets/pdf_file/0026/521297/Victorian-Climate-Change-Strategy.pdf

Victoria State Government/ DEWLP, *Water Cycle Climate Change Adaptation Action Plan 2022–2026,* https://www.climatechange.vic.gov.au/__data/assets/pdf_file/0025/558421/WaterCycleAdaptationActionPlan.pdf

Various, *Regional Climate Change Adaptation Strategies*[1], https://www.climatechange.vic.gov.au/supporting-local-action-on-climate-change#toc__id_1_regional

A.11.3 DELWP climate science investments

Victoria State Government/ DEWLP, *Victorian Climate Initiative: 2013-2016*, https://www.water.vic.gov.au/climate-change/climate-and-water-resources-research/victorian-climate-initiative

1 Regional Climate Change Adaptation Strategies (RASs) are five-year practical strategies developed by the community, supported by the Victorian Government, to address the unique challenges and opportunities that climate change brings to Victoria's regions and guide locally relevant practical action.

Victoria State Government/ DEWLP, *Victorian Water and Climate Initiative: 2017-2024*, https://www.water.vic.gov.au/climate-change/climate-and-water-resources-research/the-victorian-water-and-climate-initiative

Victoria State Government/ DEWLP/ CSIRO, *Victorian Climate Projections 2019*, https://www.climatechangeinaustralia.gov.au/en/projects/victorian-climate-projections-2019/

Victoria State Government/ DEWLP, *Victoria's Future Climate Tool*, https://vicfutureclimatetool.indraweb.io/

Victoria State Government/ DEWLP, *CoastKit*, https://www.marineandcoasts.vic.gov.au/coastal-programs/coastkit

A.11.4 Australian Government climate science investments

Climate change in Australia website, https://www.climatechangeinaustralia.gov.au/en/

Australian Rainfall and Runoff data hub website, https://data.arr-software.org/

National Climate Change Adaptation Research Facility, *CoastAdapt*, https://coastadapt.com.au/

A.11.5 Other relevant guidance

Victoria State Government/ DEWLP, *Guidelines for assessing the impact of climate change on water availability*, 2016, https://water.vic.gov.au/__data/assets/pdf_file/0014/52331/Guidelines-for-Assessing-the-Impact-of-Climate-Change-on-Water-Availability-in-Victoria.pdf

Victoria State Government/ DEWLP, *Guidelines for the development of urban water strategies*, 2021, https://www.water.vic.gov.au/__data/assets/pdf_file/0025/519802/Guidelines-for-the-development-of-urban-water-strategies_Final.pdf

Victoria State Government/ DEWLP, *Managing climate change risk: guidance for Board Members & Executives of Water Corporations and Catchment Management Authorities*, 2019, https://www.delwp.vic.gov.au/__data/assets/pdf_file/0023/428054/ISBN-Managing-Climate-Change-Risk-Guidance-Water-Entities-20190702-02-.pdf

Victoria State Government/ DEWLP, *A guide to governing in the water sector*, 2020, https://www.delwp.vic.gov.au/boards-and-governance/on-board/A-guide-to-governing-in-the-water-sector.pdf

Environmental Protection Agency (EPA) Victoria, *EPA 168 Guidelines for wastewater irrigation*, 1983, https://www.epa.vic.gov.au/-/media/epa/files/publications/168.pdf

Environmental Protection Agency (EPA) Victoria, *EPA 943 Guidelines for environmental management: biosolids land application*, 2004, https://www.epa.vic.gov.au/-/media/epa/files/publications/943.pdf

Environmental Protection Agency (EPA) Victoria, *EPA 1287 Guidelines for risk assessment of wastewater discharges to waterways*, 2009, https://www.epa.vic.gov.au/-/media/epa/files/publications/1287.pdf

Environmental Protection Agency (EPA) Victoria, *EPA 1322 Licence management*, 2017, https://www.epa.vic.gov.au/-/media/epa/files/publications/1322-9.pdf

Environmental Protection Agency (EPA) Victoria, *EPA 1707 Sewerage management guidelines*, 2020, https://www.epa.vic.gov.au/-/media/epa/files/publications/1707.pdf

Environmental Protection Agency (EPA) Victoria, *EPA 1910 Victorian guideline for water recycling*, 2021 https://www.epa.vic.gov.au/-/media/epa/files/publications/1910-2.pdf

A.11.6 Water Corporation plans and strategies

Corporate Plans, e.g., Melbourne Water Corporate Plan, https://www.melbournewater.com.au/media/3571/download

Various, *Urban water strategies*, https://www.water.vic.gov.au/liveable/urban-water-strategies

Victoria State Government/ DEWLP, *Annual Water Outlook*, https://www.water.vic.gov.au/water-reporting/outlook

Other strategies and plans which may include:

- Bushfire Mitigation Plan

- Drought Preparedness Plan
- Climate Adaptation/ Resilience Plan/ Strategy
- Melbourne Sewerage Strategy (Melbourne only)
- Sewerage strategies or masterplans
- Asset Management Plans/ Strategies