Climate Adaptation Measures

NSW Environment Protection Authority

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Executive summary

New South Wales (NSW) is highly exposed to climate change and natural hazards, having already experienced recurring and severe floods, storms, bushfires, heatwaves, and coastal erosion over the past several decades, with impacts only set to increase into the future. In this context, the NSW Environment Protection Authority (EPA) is the primary environmental regulator for NSW and has responsibilities and powers under a range of NSW environmental laws to safeguard the environment across the state. Licenses are required for certain activities under NSW environmental laws and the EPA oversees these licenced activities.

To support and inform the EPA and its licensees about approaches to climate adaptation, the EPA has engaged GHD to undertake a research project on identifying and assessing the feasibility of climate adaptation for regulated industries to reduce climate change induced environmental impacts from industrial licenses. The aim of the study is to support and encourage innovation amongst our licensees with regards to climate adaptation by providing sector specific guidance on how to address environmental risks arising from climate change.

The focus of this research is five key industries licensed by the EPA including mining, sewage treatment and sewage systems, landfills and waste processing/resource recovery facilities, intensive agriculture, and livestock processing. The study involved a literature review and engagement with subject matter specialists to confirm material environmental risks posed by climate change, identify a long list of climate adaptation measures and conduct a feasibility assessment to compare the barriers, effectiveness and cost of the proposed adaptation measures. This report is subject to, and must be read in conjunction with, the assumptions and limitations set out in Section 1.3.

The climate variables considered in this review included extreme rainfall events, drought conditions, extreme storm events, extreme heat and bushfires and rising sea levels. Each of the climate adaptation measures identified were reviewed with regard to effectiveness, barriers/constraints, and relative cost of the adaptation measures. Refer to Section 3 of the main report for a more comprehensive list of adaptation measures and the associated feasibility assessment.

In summary, a long list of climate adaptation measures was identified for each of the five regulated industries licensed by the EPA. In undertaking this review, there were some commonalities in the risks and adaptation measures identified:

– Sector specific adaptation measures and guidelines will support licensed industries in understanding and implementing climate resilience strategies.
– Ensuring ongoing monitoring and evaluation occurs so adaptation measures remain relevant and effective as climate conditions evolve.
– Promoting variance in adaptation measures and implementing nature-based solutions to avoid maladaptation and ensure long-term resilience.
– Industry guidance should be developed to ensure the consideration of ARR v4.2 Guidelines (or its latest revision) to improve rainfall and runoff predictions
– Flood, bushfire and water management plans should be updated to provide site-specific guidance that takes into consideration climate change.
– Industries that implement more stringent monitoring systems and protocols will be able to effectively respond to early warning systems and adjust to operational demands during extreme weather conditions.
– Designing industry asset infrastructure to adapt to extreme weather conditions as predicted under future climate scenarios will ensure long term sustainability of asset life and minimise environmental impact.
– Site conditions are going to change as climate risks evolve, therefore it is crucial for industries to increase routine inspections and implement more frequent maintenance checks during future construction and operational phases.

The above overarching measures need to be implemented alongside an array of sector specific adaptation measures to ensure effective management of climate risk and support long-term sustainability of the licensed industries in the face of evolving climate challenges.

The findings should support the EPA's understanding of potential climate-related risks (for the development of the EPA guidelines for example) and assist these industries in effectively managing their climate risk profile to minimise environmental risks or breaches in licence requirements, adapt to changing climate conditions, and to embed resiliency into their design and operations. It should be noted that the list is not exhaustive, and the information is generic.

Key Terminology

Key terminology	Definition
Adaptation to climate change	Process of adjustment to actual or expected climate and its effects (International Standard Adaptation to climate change – Principles, requirements and guidelines, ISO 14090:2019 (E) – definition adapted from IPCC,2014)
Adaptive capacity	Ability of a system to respond to climate change to medium potential damages, to take advantage of opportunities, or to cope with the consequences
Asset	An item, thing or entity that has potential or actual value to an organisation. The value will vary between different organisations and their stakeholders, and can be tangible or intangible, financial or non-financial (International Standard Asset management – ISO 55000:2014 (E))
APZ	Asset Protection Zone
ARR19	Australian Rainfall and Runoff Guidelines 2019 (released August 2024)
BAU	Business-as-usual
CCAP	NSW EPA Climate Change Action Plan
Climate	Statistical description of weather in terms of the mean and variability of relevant quantities over a period ranging from months to thousands or millions of years (International Standard Adaptation to climate change – Principles, requirements and guidelines, ISO 14090:2019 (E) – definition adapted from IPCC,2014)
Climate Change	Change in climate that persists for an extended period, typically decades or longer (International Standard Adaptation to climate change – Principles, requirements and guidelines, ISO 14090:2019 (E) – definition adapted from IPCC,2014)
Climate Hazard	A description of the climate variable change which is posing a risk to the premises or facility (e.g., lightning strike)
Climate Resilience	Is the ability to anticipate, prepare for, respond to, and adapt to incremental change and sudden disruptions associated with climate change
Climate Risk	The potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change.
Climate Variable	Commonly measured meteorological trends. For example, temperature, rainfall, wind, humidity
CQA	Construction Quality Assurance
Extreme weather event	Weather phenomena that are at the extremes of the historical distribution, including especially severe or unseasonal weather (AS-5334-2013)
ERS	Emergency relief structure
FOGO	Food Organics and Garden Organics
H_2S	Hydrogen sulfide
Impact	The consequences of realised risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather/climate events), exposure, and vulnerability. Impacts generally refer to effects on lives, livelihoods, health and well-being, ecosystems and species, economic, social and cultural assets, services (including ecosystem services), and infrastructure.
IPCC	Intergovernmental Panel on Climate Change
AS ISO 31000:2018	AS ISO 31000:2018 Risk management — Guidelines provide a common approach to managing any type of risk and is not industry or sector specific
Licensees / license holders	For the purpose of this report a licensee or license holders within the regulated industries looked at in this report i.e. in the mining, sewage treatment etc sectors.
POEO Act	Protection of the Environment Operations 1997
Resilience	The ability to adapt to changing conditions and prepare for, withstand, and rapidly recover from disruption

Key terminology	Definition
ROM	Run of Mine
SLR	Sea Level Rise
SMS	Subject Matter Specialist
TSS	Total Suspended Solids
WaRR Act	Waste Avoidance and Resource Recovery Act
Waste Association	Waste Management and Resource Recovery Association Australia
WSAA	Water Services Association of Australia

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1. Introduction

1.1 Background

New South Wales (NSW) is highly exposed to climate change and natural hazards, having already experienced recurring and severe floods, storms, bushfires, heatwaves, and coastal erosion over the past several decades, with impacts only set to increase into the future[1]. In this context, the NSW Environment Protection Agency (EPA) plays a crucial role in regulating and enforcing environmental laws related to licenced activities to safeguard the environment across the state.

Embedding resiliency is essential for the regulated and licensed industries in NSW as they face growing environmental risks driven by climate change, including extreme weather events, rising temperatures, and sea level rise. Industries such as energy, water, and waste management must adapt to challenges like infrastructure damage, operational disruptions, and increased regulatory demands. Building resilience involves enhancing adaptive capacity and implementing adaptation strategies, such as upgrading infrastructure, adopting sustainable practices, and incorporating nature-based solutions to mitigate risks. These measures not only protect the environment but also help ensure compliance with evolving climate policies and the long-term sustainability of industrial operations.

1.1.1 EPA: Climate change work-to-date

To support industries in managing climate risks, the EPA has developed policies and undertaken collaborations (surveys) to reduce the environmental impacts associated with licensed facilities. This is reflected in key initiatives such as the Climate Change Policy[2], Climate Change Action Plan (CCAP)[3], and the EPA Climate Change Licensee Survey[4] . This work has helped assess the environmental impact of licensees across the state and guide actions to mitigate climate risk. Alongside the ongoing work under the CCAP and survey, the EPA has developed industry sub-sector profiles that detail the specific climate hazards faced, and the adaptation measures that licensees are currently implementing.

The EPA Climate Change Licensee Survey identified that whilst many licence holders recognised the need to address climate change, there is a knowledge gap in industries regarding suitable sector-specific climate adaptations, specifically identifying a need for “more detailed guidance directly related to my sector”. This highlights the need for targeted support and clear recommendations to assist these industries in effectively managing their climate risk profile to minimise environmental risks or potential breaches in licence requirements, adapt to changing climate conditions, and to embed resiliency into their design and operations.

1.2 Purpose and scope

To support and inform the EPA and its licensees about approaches to climate adaptation, the EPA has engaged GHD to undertake a research project to identify and assess the feasibility of climate adaptation for regulated industries to reduce adverse environmental impacts from industrial licensees associated with climate change.

This research exercise is explicitly focused on the identification of climate adaptation measures in the below five industries:

1. Mining
2. Sewage treatment and sewage systems
3. Landfills and waste processing/resource recovery facilities

[1] Department of Climate Change, Energy, the Environment and Water. *New South Wales Climate Change Snapshot,* 2024 **https://www.climatechange.environment.nsw.gov.au/sites/default/files/2024-08/NARCliM2-Snapshot-NSW.pdf**

[2] Environment Protection Agency (EPA). *Climate Change Policy*. New South Wales Environment Protection Agency, 2023a. **https://www.epa.nsw.gov.au/sites/default/files/23p4264-climate-change-policy.pdf**

[3] Environment Protection Agency (EPA). Climate Change Action Plan 2023-2026. New South Wales Environment Protection Agency, 2023b. **https://www.epa.nsw.gov.au/sites/default/files/23p4265-climate-change-action-plan-2023-26.pdf**

[4] NSW EPA Climate Change Survey, October 2023. Last updated: July 2024. **https://app.powerbi.com/view?r=eyJrIjoiNjBiOWNkNWQtODdiMy00NGRmLTk3NWQtNjIxMTVkNzFiZjA2IiwidCI6Ijk2ZWY4ODIxLTJhMzktNDcxYy1iODlhLTY3YjA4MzNkZDNiOSJ9&pageName=ReportSection77bb5decda42f851d24d**

4. Intensive agriculture
5. Livestock processing

Focussing on the above five industries, the scope of works includes:

– A desktop review to confirm material environmental risks from climate change
– A desktop review supported by consultation with GHD's internal subject matter specialists to identify a long list of climate adaptation measures.
– A feasibility assessment of proposed climate adaptations, tools, and strategies considering criteria such as effectiveness, cost and barriers.

This report, supported by Appendix A, summarises the key outcomes of this research project.

1.3 Assumption and limitations

This report has been prepared by GHD for NSW Environment Protection Authority and may only be used and relied on by NSW Environment Protection Authority for the purpose agreed between GHD and NSW Environment Protection Authority as set out in section 1.2 of this report.

GHD otherwise disclaims responsibility to any person other than NSW Environment Protection Authority arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer section(s) 1.3 of this report). GHD disclaims liability arising from any of the assumptions being incorrect.

Accessibility of documents

If this report is required to be accessible in any other format, this can be provided by GHD upon request and at an additional cost if necessary.

This report is also subject to the below limitations:

– GHD has prepared this report based on information from the EPA and from publicly available sources for other agencies (both nationally and internationally). GHD has not independently verified or checked any information beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.
– This report summarises the information about environmental risks arising from climate change and relevant corresponding adaptation measures. The document is available to licensees to improve their understanding and support and encourage innovation amongst licensees but does not override the need to consider case-specific factors when making business decisions.
– The adaptation measures identified in this report are mentioned as examples and do not guarantee that a risk will be sufficiently reduced. It is the licence holder's responsibility to understand and minimise their pollution, adverse air quality, odour and ecological destruction from a changing climate for their industries. Assessment of risks from climate change need to be completed by a suitably qualified individual for each asset to understand the residual risk.
– The adaptation measures identified in this report are relevant at the time of this review. Technologies and processes will continue to develop in response to climate risks, and licensees are encouraged to continually review the climate adaptation landscape should more updated and bespoke solutions be available.

2. Methodology

Figure 1 below provides an overview of the research approach adopted for this study, with further detail provided in the subsequent sections. For the below three stages, a wide-range of sources were consulted which was supplemented by consultation with GHD's subject matter specialists.

Figure 1 Climate adaptation measures research approach

2.1 Desktop research

The desktop research involved a review of adaptation measures implemented in NSW and extended to include adaptation in other Australian jurisdictions and international sources. This research covered a wide range of sources, including the following:

– Australia
  - Climate change policies and adaptation action plans and strategies from various Australian states.
  - Department of Climate Change, Energy, the Environment and Water (DCCEEW) National Climate Risk Assessment[5]
  - Industry-specific resources related to climate adaptation
– United Kingdom
  - Environmental industry profiles from the UK government
– United States
  - Resources from the US Environmental Protection Agency on climate adaptations and risks
  - Industry-specific resources related to climate adaptation
– Other
  - Climate adaptation resources from international organisations and/or bodies e.g. United Nations Environment Programme (UNEP), Food and Agricultural Organisation (FAO), EU.
  - Relevant international case studies, academic journal articles on climate risk adaptation for various industries.

These sources collectively provided a broad range of adaptation measures and the current understanding of how adaptation measures are applied across different industries and regions. For the full list of sources that were included in the review, please refer to Appendix A.

2.2 Identification of material climate risks

In order to develop a long list of climate adaptation measures, it was critical to first understand which climate risks each of the licenced industries are most exposed and/or vulnerable to. The aforementioned sub-sector profiles developed by EPA provided insights into key climate hazards which have the potential to result in environmental risks across the five key industries to be considered in this assessment. These profiles sourced information on key climate risks from:

[5] DCCEEW 2024, National Climate Risk Assessment – first pass assessment report, Department of Climate Change, Energy, the Environment and Water, Canberra, March. CC BY 4.0.

– NSW EPA Incident Reports (2018 to present)
– NSW EPA Climate Change survey responses
– Information published by licensees on their websites or in annual reports.

Building on these risks and the findings from the desktop research, GHD's Subject Matter Specialists (SMSs) were engaged to draw upon their industry experience to identify additional climate risks with the potential to result in environmental risk and/or breach of licence conditions. Note that, 'material' in this context does not have an exact definition or environmental impact threshold, but has been used to mean 'significant' and as a way of prioritising the risks that are more commonly seen as having a meaningful impact on the environment (as confirmed by the above sources and the subject matter specialists).

2.3 Identification of climate adaptation measures

Following confirmation of the key climate risks, a three-pronged approach was used to identify potential climate adaptations and this included:

– **Desktop review:** Online literature review to identify climate adaptation measures, with a focus on adaptation measures not yet commonly used by licensees, opportunities to use existing measures in new contexts, and to seek insight on measures' feasibility, adequacy and cost-effectiveness.
– **Consultation with GHD SMS**: The research involved extensive consultation with GHD's Subject Matter Specialists, including technical directors with experience in the five licensed industries, to validate findings from the desktop review, gain industry-specific insights and identify additional climate adaptation measures. This collaboration ensured that the recommendations were both practical and tailored to the challenges each of the sector may face with climate changes.
– **Consultation with industry**: To supplement the research we reached out to industry contacts to seek further insights on their experience managing the impacts of climate change in their respective industries.

A feasibility assessment was then undertaken with the SMSs for each of the identified adaptations whereby the adaptations were classified against the following metrics:

– **Asset component**: identification of which asset component within the infrastructure or asset the adaptation was applicable to.
– **Adaptation category**: categorisation of adaptation measures based on their type

Given the broad range of assets that fall under each of the industries, it is important to note that the risks and adaptation measures have been identified at a high level and the list developed is not exhaustive.

2.4 Feasibility assessment

Following the identification of a long list of climate adaptation measures, a qualitative feasibility assessment was undertaken to enable comparison of measures and provide additional guidance to the EPA and licensees regarding the implementation of these measures. The following key criteria were used to assess the feasibility of the identified control measures:

– **Effectiveness** – Adaptation measures were assessed to determine how effective they could be at reducing the likelihood or consequence of the identified risk. This was a qualitative statement informed through the desktop research and discussions with SMSs (Table 1).
– **Barriers** – Adaptation measures were assessed to understand the barriers that could either prevent the control from being adopted or make the control more difficult for the licence holder to implement (Table 2)
– **Relative cost** – Adaptation measures were qualitatively assessed in terms of low ($), medium ($$) and high ($$$) cost. Note that these cost indications were not project or site specific and no actual costing information was reviewed in this assessment (Table 3).
– **Types of Adaptations** – Adaptation measures were categorised based on the nature of the response they represent in relation to climate risks, such as no/low regrets, accommodate, retreat, defend, and co-exist or adapt (Table 4). This classification aligns with the measures and guidance provided in the Climate Risk Ready Guide.

Table 1 Approach taken for determining effectiveness of the adaptation measure in addressing the climate risks.

Effectiveness	Definition
Low	Adaptation measures that are administrative, require implementation of plans and monitoring controls, desktop review, or require site-level policy change. The adaptation in itself does not reduce the likelihood or consequence of the environmental risk occurring as a result of climate change. They must be implemented in combination with other adaptations.
Medium	Adaptation measures that are part of a suite and collectively work to reduce the likelihood or consequence of the environmental risk occurring as a result of climate change. They could be staggered as part of an adaptation pathway.
High	Adaptation measures substantially reduce the likelihood or consequence of the environmental risk occurring as a result of climate change. This could include designing for projected climate conditions - it does not however eliminate the need for continual maintenance and review with updated climate data or guarantee that the risk is eliminated.
Enabling	Preliminary steps that enable or inform the implementation of adaptation solutions. These measures don't in themselves reduce climate risk but are a necessary first step to enable the implementation of a measure that does reduce climate risk. For example, desktop studies to inform appropriate climate change allowances for the design and construction of an asset.

Table 2 Approach taken for determining if there are any barriers/constraints of the adaptation measures against the climate risks.

Barriers/Constraints	Definition
Maturity of technology	Lack of proven technology (not just research) e.g. is there a reference available for where this measure has successfully been implemented in the past.
Commercial availability	Lack of availability of technology for implementation.
Practicality/feasibility of implementation	Difficulty in implementing the adaptation measure, due to one or multiple constraints.
Stakeholder complexity	If collaborative efforts or multi-stakeholder buy-in are required to implement or embed change. Alternatively a number of stakeholders are required to initiate and put into effect the adaptation.
Impacts to customers	Decreased level of service or impact on rates/fees.
Regulation/Guideline reform	Requires a change in regulation or reform to specify requirements (such as design guidelines).
Licence requirements and planning approvals	Need for additional planning approvals or modifications to EPA licence or the existing licence conditions are not adequate for considering climate change conditions.
Behavioural change	Implementation of adaptation measure requires behavioural change and/or on-site management practices which may be met with resistance due to priorities, biases, lack of knowledge or values.
Resources	Number, availability, and expertise of personnel to undertake the design and/or construction of the adaptation measure.
N/A	No barriers identified that would be a significant deterrent to implementation or the adaptation measure is BAU.

Table 3 Approach taken for determining relative cost of adaptation measure for the climate risks.

Cost	Definition
$	Adaptation measures requiring desktop studies including the development of Plans or Manuals, and/or when additional climate change consideration is required for an existing activity.
$$	Adaptation measures requiring procurement of additional equipment (including monitoring equipment and software), components, or materials. It may also include ongoing maintenance during operation and/or increases in cost due to changes in business as usual behaviour to accommodate climate change.

Cost	Definition
$$$	Adaptations requiring construction works to the asset.

Table 4 Approach taken for determining types of adaption actions for the climate risks.

Types of adaptation actions[6]	Definition
No/low regrets or win/win options	Are low risk responses that deliver economic benefits and should be implemented as a priority.
Accommodate	The risk is accommodated by including provisions that reduce the consequence of the impacts.
Retreat	For example, by relocating assets and people to safe areas.
Defend	Existing and new structures that work to defend against climate change affected hazards using largely structural measures.
Co-exist or adapt	The adaptation measures provide the ability to co-exist or adapt to the climate risk through a combination of innovative measures including planning.

[6] Department of Planning, Industry and Environment. *Climate Risk Ready NSW Guide: Practical Guidance for the NSW Government Sector to Assess and Manage Climate Change Risks*. State of New South Wales, 2020. **https://www.climatechange.environment.nsw.gov.au/sites/default/files/2021-06/NSW%20Climate%20risk%20ready%20guide.pdf**

3. Industry profiles

This section provides an overview of the material climate risks considered in this assessment with a focus on those resulting in adverse environmental impacts (given the remit of the EPA). This section then subsequently presents the long list of climate adaptation measures identified for each of the five industries included in this study. The adaptation measures that could be applicable across the five industries are presented upfront, providing an understanding of opportunities to use existing measures in new contexts, followed by the industry specific adaptation measures.

3.1 Overarching climate risks assessed

The climate risks identified by the EPA for assessment across the five industries (where relevant) included:

- Increased frequency, severity, and duration of extreme rainfall events leading to potential pollution of nearby waterways and/or land.
- Increased frequency and severity of drought conditions leading to adverse air quality impacts.
- Increased frequency, severity, and duration of extreme storm and rainfall events leading to potential adverse odour impacts.
- Increased frequency, and severity of extreme heat and bushfires leading to fires at licenced facilities or damage to infrastructure resulting in adverse air quality impacts and potential ecological destruction.

In addition to these, the desktop research and discussions with the SMSs revealed that the following climate risks were deemed material for some of the industries in assessing and developing a more comprehensive register of climate adaptations:

- Rising sea levels leading to inundation of coastal infrastructure resulting in potential water and land contamination.
- Extreme weather events (temperatures, rainfall, storms) leading to critical equipment going offline resulting in potential odour impacts, pollution to the environment (water and land) or reduced air quality (odour).

3.2 Overarching adaptation measures

This work highlights that many of the potential impacts of the climate hazards and adaptation measures may apply across the five industries. This was established through the desktop review and supported through consultation with the SMSs.

Table 5 Summary of common adaptation measures found across all five licensed industries.

Adaptation	Description
Mandating the use of the latest guidelines with the most recent climate change factors	The Australian Rainfall and Runoff (ARR) Guidelines v4.2, or its latest revision, was released last year and includes updated climate factors to improve rainfall and runoff predictions. These guidelines are essential for hydrological assessments, infrastructure design, and flood risk management. In the context of climate adaptation, the ARR v4.2 Guidelines (or latest revision available) play a critical role by incorporating updated methodologies that reflect changing rainfall patterns and extreme weather events as a result of climate change. These guidelines enable licensed industries to meet requirements for current climate conditions and future climate scenarios and manage projected rainfall intensities.
Updating and implementing flood and fire (bushfire) management plans	The development and regular updating of flood and fire management plans, aligned with Fire and Rescue NSW and the Australian Rainfall and Runoff (ARR) v4.2 guidelines, or the latest revision available are critical for addressing evolving climate conditions. Infrastructure should be designed and constructed according to an updated Flood and Bushfire Risk Management Plan that

Adaptation	Description
	incorporates climate change considerations, with risk assessment regularly updated to address future conditions.
Implementation of real-time automated monitoring systems, more stringent protocols including early warning systems to respond to changes in operational conditions	Implementing real-time automated monitoring and early warning systems to continuously track key parameters will enable proactive maintenance and timely response to changes in operational conditions. Enhanced monitoring frequency may be required during periods of heightened vulnerability
Designing asset infrastructure for extreme weather conditions as predicted under future climate scenarios	Designing downstream drainage systems to withstand extreme weather conditions is critical for effective water management and erosion control. These designs should ensure adequate water conveyance and minimise environmental impact.
Implementation of coverings of site assets to accommodate varying site conditions and regulation requirements	Appropriate daily coverings of site assets are essential for minimising odour generation and managing contamination and pollution risks. These specific adaptation measures should be tailored to site conditions and regulatory requirements.
Increasing routine inspections to adjust for climate change.	Routine inspections of sites. Inspection frequency should be adjusted as climate conditions change and relevant requirements are released alongside operational and construction plans.
Implementing dust suppression measure as climate conditions change	Dust suppression measures should be employed to mitigate wind-borne dust emissions. Consideration should be given to both practical and aesthetic solutions.
Enhanced maintenance and inspections of site equipment and assets as issues arise.	Perform regular maintenance and inspections of equipment, systems and assets to ensure proper functioning and prevent disruptions.

3.3 Mining

3.3.1 Mining: overview

The EPA regulates the minerals mining, coal mining, and petroleum exploration industries under the *Protection of the Environment Operations Act 1997* (PoEO Act). This includes overseeing a range of mining activities, such as underground and surface mining for minerals (including coal), mineral processing, mineral waste generation, coal works, and petroleum exploration, assessment and production operations. To prospect or mine for any mineral in New South Wales, or to conduct ancillary mining activities, companies must obtain authorisation from the NSW Resources Regulator under the *Mining Act* 1992. The EPA ensures that the mining industry complies with these Acts to minimise their impact on the environment. Another key aspect under the Mining Act 1992 is EPA enforcement of rehabilitation requirements. This aligns with the EPA wanting to implement adaptation measures in the mining industry and continuing to provide advice and rehabilitation strategies to ensure compliance with regulatory requirements. The POEO and Mining Acts impose conditions on licences to ensure effective rehabilitation of mining sites, which help to facilitate the industry's transition towards a more sustainable sector

In summary, this climate adaptation measures research study identified a total of 70 adaptation measures for the mining sector, categorised as below[7]:

- 11 desktop assessments
- 29 engineered solutions
- 10 manuals, plans, policies, and procedures
- 15 monitoring protocols
- 3 behavioural measures
- 4 nature-based solutions.

[7] Noye that two adaptation measures were identified under both Manuals, Plans, Policies and Procedures, and Behavioural.

Table 6 provides the long list of these adaptation measures and the associated feasibility assessment.[8] The adaptation measures identified ranged in effectiveness, with the 'engineered solutions' making up a majority of the 'High' effectiveness measures (i.e. 20 out of 22 'High' measures were engineered solutions), with the 'Medium and 'Low' categories, comprising a mix of the remaining measures.

In this instance, the 'Enabling' solutions were exclusively ''Desktop studies', often requiring the consideration of climate scenarios during design of various infrastructure solutions. In most instances, although not all, the highly effective, 'Engineered solutions' were also identified as having a high cost (i.e. $$$), and the less effective desktop studies and monitoring protocols were associated with lower costs ($, $$).

The fewer nature-based solutions identified, highlight that this is an underdeveloped area, requiring more industry research and buy-in particularly regarding the long-term costs and benefits of these.

A key finding from the desktop review is that while industries like mining already implement significant fire, water and dust management measures, these actions are often not directly framed through the lens of climate change, with climate adaptation benefits being secondary. The mining industry, like most others, would benefit from incorporating climate change considerations early on in planning and design and will require location and asset specific climate adaptation.

[8] Note that Table 7 has not included measures that were classified as overarching and were therefore included in Table 5.

3.3.2 Mining: Climate adaptation measures

Climate adaptation measures identified for the mining industry in response to the climate change induced environmental risks (outlined in Section 3.1), have been identified in Table 6 below.

Table 6 Climate adaptation measures - Mining

Adaptation measure	Asset Component	Adaptation category	Feasibility Assessment		
			Effectiveness	Barriers	Cost
Risk 01: Increased frequency, severity, and duration of extreme rainfall events leading to potential pollution of nearby waterways and/or land.					
Sensitivity testing should be done using the Australian Rainfall and Runoff (ARR) Guidelines (v4.2 or latest revision available) to assess the capacity of existing water storage. They should be assessed to determine if projected rainfall intensities can be adequately captured and stored without potential breach of licence requirements.	All water storage dams	Desktop Assessment	Enabling	N/A	$
Capacity of existing infrastructure may need to be upgraded to cope with projected increases in rainfall intensities. The exact adaptation measure will depend on the outcomes of the desktop assessment. Some upgrade works could include increasing the height of the dam wall, widening or deepening the spillway.	All water storage dams	Engineered Solution	High	Practicality/feasibility of implementation Licence requirements and planning approvals	$$$
Design and construct provisions for contingency containment (in addition to BAU design storage allowances) to manage excess inflows during extreme events. Contingencies will include emergency spillways, real-time monitoring systems, Emergency Action Plans, backup power supply, and secondary (emergency) containment basins in the event of a breach.	All water storage dams	Engineered Solution	High	Practicality/feasibility of implementation Licence requirements and planning approvals Regulation/Guideline reform	$$$
Dewatering of dams (and release to nearby waterways) prior to periods of heavy rainfall, provided the water quality meets licence requirements. This will increase storage capacity of the dam during heavy rainfall events.	All water storage dams (except contaminated water including tailings dams)	Engineered Solution	Medium	Practicality/feasibility of implementation	$$
Implement erosion and sediment control plans and slope stabilisation plans.	Dam embankments	Manuals, Plans, Policies, and Procedures	Low\	Practicality/feasibility of implementation	$
Implement groundwater control measures as required across the site in areas of close proximity to high contamination risk. Groundwater controls could include pumping wells near the embankment, armouring of the embankment, upgrading toe drainage systems, sheet piling, and dewatering. The exact adaptation implemented will depend on the site conditions.	Dam embankments	Monitoring Protocols	High	Practicality/feasibility of implementation Licence requirements and planning approvals	$
Desiccation of embankments (compromising structural integrity) can be prevented by planting native low root grasses. This can prevent pollution of surface water by reducing run-off during extreme rainfall events.	Dam embankments	Nature Based Solution	Medium	Practicality/feasibility of implementation	$$
Ensure there is sufficient redundancy in the system to maintain critical operations during heavy rainfall and flooding events to prevent overflows. This could include additional pumps and alternative infrastructure pathways.	Site wide	Engineered Solution	High	Practicality/feasibility of implementation Licence requirements and planning approvals	$$$

Adaptation measure	Asset Component	Adaptation category	Feasibility Assessment		
			Effectiveness	Barriers	Cost
Undertake or update existing flood studies for the site under the changed climate conditions. This should take into consideration the climate change factors presented in the Australian Rainfall and Runoff Guideline ARR19v4.2 (or the latest revision of this guideline available).	Site wide	Desktop Assessment	Enabling	N/A	$
Relocation, raising, or implementation of flood protection measures for key infrastructure (e.g. levee, armour dam embankments).	Site wide	Engineered Solution	High	Practicality/feasibility of implementation Licence requirements and planning approvals	$$$
Geotechnical assessment on slope stability under future rainfall scenarios. Unstable landforms can lead to landslides.	Site wide	Desktop Assessment	Enabling	N/A	$$
Based on geotechnical findings of slope stability, engineered solutions relevant to the site will need to be designed and constructed (e.g. batter reprofiling, buttressing, slope reinforcement (vegetation/geotextiles)).	Site wide	Engineered Solution	High	Practicality/feasibility of implementation Licence requirements and planning approvals	$$$
Sensitivity testing should be done using the Australian Rainfall and Runoff (ARR) Guidelines (v4.2 or latest revision available) to assess the capacity of spillways. They should be assessed to determine if projected rainfall intensities can be adequately conveyed.	Spillways	Desktop Assessment	Enabling	N/A	$
Capacity of existing spillway infrastructure may need to be upgraded to cope with projected increases in rainfall intensities. Some upgrade works could include increasing the height of the dam wall (deepens spillway) or widening the spillway.	Spillways	Engineered Solution	High	Practicality/feasibility of implementation Licence requirements and planning approvals	$$$
Existing or new surface water controls (including drainage) to be assessed according to the Australian Rainfall and Runoff (ARR) Guidelines (v4.2 or latest revision available). This will enable more accurate sizing of water management and containment systems.	Surface water management	Desktop Assessment	Enabling	N/A	$
Design and construct surface water controls (including drainage) to manage operational and post-closure flows.	Surface water management	Engineered Solution	High	Practicality/feasibility of implementation Licence requirements and planning approvals	$$$
Implement remote water quality logs at discharge points and upstream and downstream of the site boundary (monitor TSS, pH and other licensing requirements) to trigger if there are potential pollution incidents occurring.	Surface water management	Monitoring Protocols	Low	N/A	$
Monitor rate and quality of seepage for existing tailings dams.	Tailings dam	Monitoring Protocols	Low	N/A	$$
Install liners or barriers on existing tailings dams	Tailings dam	Monitoring Protocols	Low	N/A	$$$
Seepage from a tailings dam can be managed through seepage capture and interception systems such as interception bores where the water is pumped from the bore to a sump and then back into the dam. Tailings beach design can reduce hydraulic pressure and seepage rate. Physical barriers such as grout curtain and cutoff walls can also be used.	Tailings dam	Engineered Solution	High	Practicality/feasibility of implementation Licence requirements and planning approvals Regulation/Guideline reform	$$$
Increase capacity of tailings dam.	Tailings dam	Engineered Solution	High	Practicality/feasibility of implementation	$$$

Adaptation measure	Asset Component	Adaptation category	Feasibility Assessment		
			Effectiveness	Barriers	Cost
				Licence requirements and planning approvals	
Risk 02: Increased frequency and severity of drought conditions leading to adverse air quality impacts.					
Desiccation of embankments (compromising structural integrity) can be prevented by planting native low root grasses. This can prevent dust generation and erosion of the embankment	Dam embankments	Nature Based Solution	Medium	Practicality/feasibility of implementation	$$
Monitor and maintain haul roads to minimise dust generation which may require regrading or leveling.	Haul roads	Monitoring Protocols	Medium	Practicality/feasibility of implementation	$$
Enclosing dust generating processes such as grinding/crushing plant and machinery, conveyors, chutes, or drills equipped with dust collection systems or automated dust suppression systems.	Material processing	Engineered Solution	High	N/A	$$
Reducing the drop height from which overburden or mined material is tipped (during any part of the process) can reduce dust generated.	Material transfer locations	Engineered Solution	Medium	N/A	$
Design and construct a hood at ROM (Run of Mine) bins.	Material transfer locations	Engineered Solution	Medium	N/A	$$
Implement automated dust suppression systems at ROM bins to spray ore as it is transferred to the bin.	Material transfer locations	Engineered Solution	High	N/A	$$
Increase wall height of ROM bins	Material transfer locations	Engineered Solution	Medium	N/A	$$
Blasting to occur when there is low wind. There is often an onsite local weather station to aid in monitoring weather conditions. This is BAU practice.	Mine pit	Behavioural	Medium	N/A	$
Optimise haulage distances. This could be achieved through in-put crushing and conveying systems though changing systems /mechanisms is often calculated based on economic feasibility of hauling rather than for environmental benefits.	Mine pit Material processing	Behavioural and manuals, plans, policies & procedures	Medium	Practicality/feasibility of implementation Licence requirements and planning approvals Regulation/Guideline reform	$$$
Capturing, treating, and storing flood/rainwater into aquifers (managed aquifer recharge). This can be drawn upon during periods of drought for dust suppression. This would require the acquisition of water sharing agreements (if available and appropriate for each site) as water harvesting can be an issue.	Site wide	Engineered Solution	High	Practicality/feasibility of implementation Licence requirements and planning approvals Regulation/Guideline reform	$$$
Optimising water droplet size to capture more dust with less water volumes. Using water carts with atomisers is beneficial in generating consistent droplet size and maintaining high velocity.	Site wide	Engineered Solution	Medium	N/A	$$
Implement use of polymer-based sprays for dust suppression.	Site wide	Engineered Solution	Medium	Maladaptation	$
Increase the number of water carts on site.	Site wide	Engineered Solution	High	Practicality/feasibility of implementation Licence requirements and planning approvals	$$
Implement automated sprinkler systems on haul roads and across the site at high dust generation locations.	Site wide	Engineered Solution	High	Practicality/feasibility of implementation	$$

Adaptation measure	Asset Component	Adaptation category	Feasibility Assessment		
			Effectiveness	Barriers	Cost
Covering loads as they are transported out of the mine. This is best practice methods, though is often not implemented on site.	Site wide	Behavioural and manuals, plans, policies & procedures	High	Behavioural change	$
Implementation of smart monitoring systems, such as Oizom, to monitor and provide alerts to air quality across a site.	Site wide	Monitoring Protocols	Low	N/A	$$
Progressive rehabilitation efforts to minimise exposed site during operation of the mine. This is often a requirement as part of mine lease requirements (especially open cut).	Site wide	Engineered Solution	Medium	Practicality/feasibility of implementation Licence requirements and planning approvals Regulation/Guideline reform	$$
Reassess site water balance under projected climate conditions.	Site wide	Desktop Assessment	Enabling	N/A	$
Investigate feasibility of implementing desalination plants to maintain adequate water supplies for onsite activities and dust suppression.	Water treatment infrastructure	Desktop Assessment	Medium	N/A	$
Based on outcome of desktop assessment implement desalination plants to maintain adequate water supplies for onsite activities and dust suppression.	Water treatment infrastructure	Engineered Solution	High	Practicality/feasibility of implementation Licence requirements and planning approvals Regulation/Guideline reform	$$$
Assess the capacity of existing water treatment systems to treat increased volumes of water (surface water, drawn from the sedimentation basin or tailings dam, etc) for beneficial reuse to manage dust.	Water treatment infrastructure	Desktop Assessment	Enabling	N/A	$
Increase the capacity of existing water treatment and storage infrastructure to process and retain increased volumes of water for beneficial reuse.	Water treatment infrastructure	Engineered Solution	High	Practicality/feasibility of implementation Licence requirements and planning approvals	$$$
Risk 03: Increased frequency, severity, and duration of extreme storm events leading to potential adverse odour quality impacts.					
N/A for mining industry.					
Risk 04: Increased frequency, and severity of extreme heat and bushfires leading to fires at licenced facilities or damage to infrastructure resulting in adverse air quality impacts and potential ecological destruction.					
Provisions for hot works should be within approved areas, e.g. workshops and facilities where there are sufficient fire management protocols in place.	Hot works Materials processing	Manuals, Plans, Policies, and Procedures	Medium	N/A	$
Implement Vegetation Management Plans. Maintaining vegetation can prevent potential ecological destruction and can help to manage natural fuel sources around the site.	Site wide	Nature Based Solution	Low	N/A	$
Prepare Fire Management Plans, in addition to a Fire Risk Assessment aligned with Fire and Rescue NSW's Fire safety guideline, or the latest revision available, which	Site wide	Manuals, Plans, Policies, and Procedures	Low	N/A	$

Adaptation measure	Asset Component	Adaptation category	Feasibility Assessment		
			Effectiveness	Barriers	Cost
covers (at a minimum) procedures and protocols for storage of materials and emergency measures in the case of a fire.					
Prepare a Bushfire Management Plan for the site with appropriate asset protection zones surrounding the site. The minimum distances between vegetation and the mine site may need to increase. The Plan should be revised and updated at appropriate intervals especially as climate conditions change in the future.	Site wide	Manuals, Plans, Policies, and Procedures	Low	N/A	$
Provide sufficient fire suppression tools and training to staff.	Site wide	Manuals, Plans, Policies, and Procedures	Medium	N/A	$
Trigger stop work conditions (code red) during lightning strikes as there is high risk of fires igniting.	Site wide	Manuals, Plans, Policies, and Procedures	High	N/A	$
Monitoring of underground temperatures at legacy sites where fires can generate.	Site wide	Monitoring Protocols	Low	N/A	$
Implement thermal monitoring protocols for stockpiles.	Stockpiles	Monitoring Protocols	Low	N/A	$
Optimise design and management of stockpiles to minimise likelihood of spontaneous combustion during extreme heat events. There are standard stockpile management procedures in place on how to stockpile, how long they should remain, and how they should be moved around.	Stockpiles	Manuals, Plans, Policies, and Procedures	Medium	Practicality/feasibility of implementation	$
Consistent turnover of stockpiles during periods of extreme heat to maintain oxygen to the material and to minimise opportunity for spontaneous combustion.	Stockpiles	Manuals, Plans, Policies, and Procedures	Medium	N/A	$
Risk 05: Rising sea levels leading to inundation of coastal infrastructure resulting in potential water and land contamination.					
Assess the impact of sea level rise on the external embankments. Stability and erosion are of concern.	Dam embankments	Desktop Assessment	Enabling	N/A	$
Assess the impact of sea level rise on the structural components. Increased pore pressure can result in structural elements 'popping' from the ground due to buoyancy effects - the stability of the structural components can be compromised. The Factor of Safety applied in design may need to change to accommodate for these projected conditions.	Site wide	Desktop Assessment	Enabling	N/A	$
Implement natural barriers such as mangroves and wetlands to buffer against wave erosion.	Site wide	Nature Based Solution	Medium	Practicality/feasibility of implementation Licence requirements and planning approvals	$$$
Implement seawalls or levees to provide physical barriers protecting against coastal flooding and erosion.	Site wide	Engineered Solution	Medium	Practicality/feasibility of implementation Licence requirements and planning approvals	$$$

3.4 Sewage treatment and sewage systems

3.4.1 Sewage overview

The EPA regulates the wastewater industry under the PoEO Act. This includes overseeing the sewage treatment, discharge, contaminated groundwater treatment and reuse of wastewater to protect the environment and water resources. Wastewater facilities operating under the EPA licenses must comply with strict environmental standards outlined in the POEO Act, which aims to minimise pollution and environmental impact, including the safe management of wastewater discharges into local waterways. Through continuous guidance and support, the EPA helps the wastewater sector meet regulatory requirements and contribute to the long-term sustainability of the state's water resources.

In summary, this desktop study identified a total of 59 adaptation measures for sewage treatment and sewage systems, categorised as follows:

– 9 desktop assessments
– 28 engineered solutions
– 9 manuals, plans, policies, and procedures
– 4 collaboration measures
– 5 monitoring protocols
– 2 behavioural measures
– 2 nature-based solutions.

Table 7 provides the long list of these adaptation measures and the associated feasibility assessment.[9] A key finding of this study is that the sewage treatment industry often has well-established practices for monitoring key parameters and conducting climate modelling for drainage systems, though these systems should be updated in line with updated versions of ARR v4.2 guidelines (or latest revision available) and future climate modelling as climate conditions change

Another key insight regarding climate adaptation, is that whilst there is a large number of ‘Engineered solutions’ available (i.e. 48% of the measures identified were engineered solutions), climate risk also needs to be proactively addressed at the strategic framework level. That is, there needs to be a comprehensive, overarching and long-term consideration of climate change at the strategic level in order to facilitate systemic climate resilience.

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[9] Note that Table 7 has not included measures that were classified as overarching and were therefore included in Table 5.

3.4.2 Sewage: Climate adaptation measures

Climate adaptation measures identified for the sewage treatment industry in response to the climate change induced environmental risks (outlined in Section 3.1), have been identified in Table 7 below.

Table 7 Climate adaptation measures - Sewage

Adaptation measure	Asset Component	Adaptation category	Feasibility Assessment		
			Effectiveness	Barriers	Cost
Risk 01: Increased frequency, severity, and duration of extreme rainfall events leading to potential pollution of nearby waterways and/or land.					
Use dynamic flow control systems (e.g., adjustable weirs, smart valves) to optimise the use of existing storage and improve flow management without requiring large-scale expansions.	Mains network	Engineered Solution	High	Practicality of implementation Impacts to customers Regulation/Guideline reform Licence requirements and planning approvals	$$$
Build redundancy into sewerage networks to allow for alternative pathways or additional capacity during peak events. E.g. when upgrading network - assess capacity to design and construct parallel pipelines.	Mains network	Engineered Solution	Medium	Practicality of implementation	$$-$$$
Collaborate with councils and/or relevant agencies to reduce stormwater inflows through proactive measures such as sealing manholes, improving and upgrading sewerage networks (relining pipes and managing illegal connections). Consider decentralised stormwater management solutions, such as rain gardens or permeable pavements, to reduce inflow pressure on sewer systems.	Mains network	Collaboration	Medium	Stakeholder complexity Practicality of implementation	$-$$$
Collaboration between intergovernmental agencies to set clear targets and focus on private and commercial properties to prevent inflow as much as practicable.	Mains network	Collaboration	Medium	Stakeholder complexity Practicality of implementation	$$$
Collaborate with councils and/or relevant agencies to reduce stormwater inflows by improving QA/QC of new private property drain installations, identification of inflows from house roof's cross connections from stormwater inflows and infiltration from leaking private drainage pipes.	Mains network	Collaboration	Medium	Stakeholder complexity Practicality of implementation	$-$$$
Design of new systems to ensure no emergency relief structures (ERS) are required in the future. That is, a greater intensity and frequency of rainfall will require a shift in design standards to effectively mitigate discharges. (i.e., wet weather /dry weather ratios should be updated).	Mains network	Engineered Solution	Medium	Behavioural change Regulation/Guideline reform	$
More effective management of existing ERS required so that no more is allowed to discharge than is absolutely necessary.	Mains network	Manuals, Plans, Policies, and Procedures	Low	Behavioural change Practicality/feasibility of implementation Regulation/Guideline reform	$
Undertake sewer and manhole renewals and schedule additional preventative maintenance of low-lying sewer assets to minimise stormwater infiltration.	Mains network	Manuals, Plans, Policies, and Procedures	Medium	Practicality of implementation	$$$

Adaptation measure	Asset Component	Adaptation category	Feasibility Assessment		
			Effectiveness	Barriers	Cost
Design and construct increased hydraulic and treatment capacity of existing water management systems to process higher inflows (as determined in the desktop assessment that accounts for climate change projections).	Mains network Pumping stations Treatment plants	Engineered Solution	High	Regulation/Guideline reform Licence requirements and planning approvals Resources Stakeholder complexity	$$$
Initiate overflow management protocols if real-time monitoring has indicated likelihood of overflow. Emergency overflow solutions, such as temporary storage or controlled bypasses, should be sized according to projected climate change conditions in order to mitigate risk of untreated wastewater being discharged.	Mains network Pumping stations Treatment plants	Engineered Solution	Medium	Practicality of implementation Impacts to customers Licence requirements and planning approvals	$$$
Perform a health check on the existing sewer assets (blockages, breaks or chokes) that could enable excess inflow and infiltration.	Mains network Pumping stations Treatment plants	Monitoring Protocols	Low	N/A	$$
Address existing defects in the sewer assets (blockages, breaks or chokes) to prevent excess inflow and infiltration. This could include relining or upgrade works.	Mains network Pumping stations Treatment plants	Engineered Solution	Medium	Practicality of implementation Regulation and guideline reform	$$$
Prioritisation and investment in maintenance of existing assets to maximise the efficiency of the existing infrastructure. Frequency of maintenance may need to increase over time under climate change conditions to reduce choke points. This includes corrective, emergency, and preventative maintenance works.	Mains network Pumping stations Treatment plants	Manuals, Plans, Policies, and Procedures	Medium	N/A	$
Develop seasonal preparedness plans to pre-emptively create capacity during high-risk wet seasons.	Mains network Pumping stations Treatment plants	Manuals, Plans, Policies, and Procedures	Low	N/A	$
Future designs and construction of emergency overflow tanks, lagoons, and pipelines are modular and adaptable, allowing for phased expansions based on updated climate projections.	Mains network Pumping stations Treatment plants	Engineered Solution	High	Stakeholder complexity Practicality of implementation	$-$$$
Assess existing hydraulic performance to understand the influence of rising water levels on the system from increased water levels at discharge points. Grade may need to change for existing designs. River flooding and tidal influence should be considered and designed for new designs.	Mains network Pumping stations Treatment plants	Desktop Assessment	Enabling	Practicality of implementation	$-$$$
Develop a resilience plan for the network, pumping stations, and treatment plants to ensure it is robust and has buffering capacity to maintain efficient operation in the future.	Mains network Pumping stations Treatment plants	Manuals, Plans, Policies, and Procedures	Low	N/A	$
Review the capacity of the existing infrastructure to adequately convey flows under projected climate conditions. The Australian Rainfall and Runoff Guideline ARR19v4.2 (or the latest revision of this guideline available) should be referenced when undertaking this assessment.	Mains network Pumping stations Treatment plants	Desktop Assessment	Enabling	Regulation/Guideline reform Licence requirements and planning approvals	$
a) Update Flood Risk Management Modelling/Plan with the lens of climate change applied.	Mains network Pumping stations Treatment plants	Manuals, Plans, Policies, and Procedures	Low	Licence requirements and planning approvals	$
b) Implementation of designs and construction of infrastructure in accordance with updated Flood Risk Management Plans.	Networks	Engineered Solution	Medium	Regulation/Guideline reform Licence requirements and planning approvals	$-$$$

Adaptation measure	Asset Component	Adaptation category	Feasibility Assessment		
			Effectiveness	Barriers	Cost
				Resources Stakeholder complexity	
Implementation of designs and construction of infrastructure in accordance with updated Flood Risk Management Plans.	Networks	Engineered Solution	Medium	Regulation/Guideline reform Licence requirements and planning approvals Resources Stakeholder complexity	$-$$$
Assess impacts from updated catchment modelling on pumping stations and treatment plants. This should take into consideration the climate change factors presented in the Australian Rainfall and Runoff Guideline ARR19v4.2 (or the latest revision of this guideline available).	Pumping stations Treatment plants	Desktop Assessment	Enabling	Regulation/Guideline reform Licence requirements and planning approvals	$
Design and construct provisions for contingency containment (e.g. emergency detention basins), to manage excess inflows during extreme events (catering for projected climate change conditions).	Pumping stations Treatment plants	Engineered Solution	High	Regulation/Guideline reform Licence requirements and planning approvals Resources Stakeholder complexity	$-$$$
Assess impact of extreme rainfall events on the environment with existing current waste water management infrastructure to determine extent of required infrastructure or processing upgrades.	Site wide	Desktop Assessment	Enabling	Regulation/Guideline reform Licence requirements and planning approvals	$
Assess impact of extreme rainfall events on the environment and the impact on future waste water management infrastructure to determine the cause and effect on the environment to determine if additional expenditure is required.	Site wide	Desktop Assessment	Enabling	Regulation/Guideline reform Licence requirements and planning approvals	$
Upgrade Asset Management Plan and Overflow Management Plan to ensure regular maintenance is prescribed and that climate change parameters are taken into account.	Site wide	Manuals, Plans, Policies, and Procedures	Low	Licence requirements and planning approvals	$
Implementation of upgraded Asset Management Plan and Overflow Management Plan	Site wide	Engineered Solution	Medium	Practicality of implementation Impacts to customers	$$$
Design and construct balance tanks or open storage tank/ponds to divert and manage increased inflow to the treatment plant. Flows are diverted until there is capacity in the system to treat the water.	Treatment plants	Engineered Solution	Medium	Practicality of implementation	$$$
Embed redundancy in the treatment plant processes and infrastructure to ensure if one element goes offline the plant can still remain functional, preventing harmful discharges	Treatment plants	Engineered Solution	Medium	Practicality of implementation Regulation and guideline reform	$$$
Risk 02: Increased frequency and severity of drought conditions leading to adverse air quality impacts including dust and odour.					
Chemical dosing along the sewerage network to manage odour. The frequency of dosing may need to increase over time.	Mains network	Engineered Solution	Medium	Licence requirements and planning approvals Practicality of implementation Maladaptation	$$
Review capacity of existing vent stacks along the network.	Mains network	Desktop Assessment	Enabling	Licence requirements and planning approvals Practicality of implementation	$

Adaptation measure	Asset Component	Adaptation category	Feasibility Assessment		
			Effectiveness	Barriers	Cost
Upgrade vent stacks to treat high concentrations of odour. More mechanical filtration devices or filter beds (bio filters) may be required along the network with larger capacity to manage odour during dry periods.	Mains network Pumping stations	Engineered Solution	High	Licence requirements and planning approvals Practicality of implementation	$$
Implementation of additional filters along the network at exit valves to reduce odour release. Maintenance of these is key to ensuring efficiency. Maintenance requirements should be captured in operational management plans.	Mains network Pumping stations	Engineered Solution	Medium	Practicality of implementation Regulation and guideline reform	$$
Flushing the system to minimise issue of sedimentation in dry weather flows.	Mains network Pumping stations	Engineered Solution	Medium	Licence requirements and planning approvals Practicality of implementation	$$$
Undertake odour dispersion modelling under projected climate conditions to understand the extent to which air quality impacts may be felt, and where they may be more concentrated.	Mains network Pumping stations Treatment plants	Desktop Assessment	Enabling	N/A	$
Assess effectiveness of current odour control mechanisms/systems and investigate if multiple management modes are required considering changes anticipated under climate change (i.e. less rainfall).. Odour control mechanisms include odour covers, biofilters, bio trickling filters, chemical scrubbers, activated carbon adsorption, chemical dosing, UV/Ozone oxidation etc.	Mains network Pumping stations Treatment plants	Desktop Assessment	Enabling	N/A	$
Water and wastewater industries to collaborate to enhance and implement the WSAA (Water Services Association of Australia) codes incorporating climate change considerations and to improve resiliency of water infrastructure.	Mains network Pumping stations Treatment plants	Collaboration	High	Stakeholder complexity	$$
Use of modelling software, such as SeweX, which has been used internationally (and in Australia) to efficiently manage odour and corrosion in the wastewater network.	Mains network Pumping stations Treatment plants	Desktop Assessment	Enabling	N/A	$$-$$$
Increase the aeration pond capacity and increase the rate of aeration to prevent odour development and processes turning anerobic.	Treatment plants	Engineered Solution	Medium	N/A	$$
Consider switching to or retrofitting systems with advanced biological processes (e.g., anoxic/oxic or membrane bioreactors) that are less sensitive to reduced oxygen levels during heatwaves.	Treatment plants	Engineered Solution	Medium	Practicality of implementation	$$$
Optimise existing aeration systems by using variable frequency drives to adjust aeration levels based on real-time dissolved oxygen demand.	Treatment plants	Engineered Solution	Medium	Practicality of implementation	$$$
Risk 03: Increased frequency, severity, and duration of extreme storm events leading to potential adverse odour quality impacts.					
Odour is not often a concern during storm/heavy rainfall events. The key concern is overflow issues which has been captured in the first risk statement.					
Risk 04: Increased frequency, and severity of extreme heat and bushfires leading to fires at licenced facilities resulting in adverse air quality impacts and potential ecological destruction.					
Specify improved heat/fire resistant materials for above ground pipes. Sections of the network that are in bushfire prone lands may require application of a fire-resistant material.	Mains network	Engineered Solution	Medium	N/A	$$
Log offsite odour complaints and assess ability to modify operational practice to reduce odour risk (if possible). This could be through developing a community odour alert system enabling residents to report odours in real time through apps/hotlines.	Mains network Pumping stations Treatment plants	Behavioural	Low	Impacts to customers Stakeholder complexity	$

Adaptation measure	Asset Component	Adaptation category	Feasibility Assessment		
			Effectiveness	Barriers	Cost
Upgrade ventilation systems and odour control systems (such as biofilters, activated carbon, chemical dosing - control measure chosen will depend on a number of variables.)	Mains network Pumping stations Treatment plants	Engineered Solution	Medium	N/A	$$
Existing sites could be retrofit with materials more heat/fire resistant and/or shading systems should be implemented to protect vulnerable equipment and components.	Pumping stations Treatment plants	Engineered Solution	Medium	Practicality of implementation	$$$
Installation of online odour (H_2S) systems and multi-gas detectors which can detect a range of compounds including methane, ammonia, and VOCs. The online system allows for continuous measurement.	Pumping stations Treatment plants	Monitoring Protocols	Medium	Practicality of implementation	$$
Update and implement a Bushfire Management Plan for exposed sites including strategic fuel reduction activities and staff training.	Pumping stations Treatment plants	Manuals, Plans, Policies, and Procedures	Medium	N/A	$
Install firefighting and containment methods including sprinkler systems (potentially triggered by smoke detectors or thermal cameras), fire suppression, fire water storage tanks (freshwater/rainwater/stormwater that has not been in contact with waste), temperature monitoring sensors/mechanisms and sufficient and easily accessible fire hydrants.	Pumping stations Treatment plants	Behavioural	Medium	N/A	$
Increase Asset Protection Zones (APZs) as required for climate change per relevant requirements.	Pumping stations Treatment plants	Nature Based Solution	Medium	N/A	$
Risk 05: Extreme weather events (temperatures, rainfall, storms) leading to treatment facilities going offline resulting in potential odour impacts and untreated flows to the environment (water and land) or reduced air quality (odour).					
Elevating or flood proofing of critical components and remote operation capability of critical systems e.g. electrical systems and control rooms, so they aren't flooded.	Pumping stations Treatment plants	Engineered Solution	High	Practicality of implementation	$$$
Assess additional requirements for generators or backup power supplies onsite in the instance that power is cut to the site. Critical infrastructure should be connected to these backup supplies to avoid complete site shutdown.	Pumping stations Treatment plants	Engineered Solution	High	Practicality of implementation Impact to customers	$$$
Relocation of the facility or partial relocation of critical components to higher ground (if available on the existing site) to prevent flooding and systems going offline.	Pumping stations Treatment plants	Engineered Solution	High	Practicality of implementation Impact to customers	$$$
Risk 06: Rising sea levels leading to inundation of coastal infrastructure resulting in potential water and land contamination					
Assess and implement or enhance natural barriers such as mangroves or tidal marshes to protect coastal inundation and storm surge.	Mains network Pumping stations Treatment plants	Nature Based Solution	Enabling	Practicality of implementation Licence requirements and planning approvals	$$$
Update Asset Management Plan, Floodplain Risk Management Plans and Coastal Management Manual or Plan with the lens of climate change applied. Appropriate climate change factors should be considered in the updated Plans and Manuals.	Site Wide	Manuals, Plans, Policies, and Procedures	Low	N/A	$
Implementation of upgraded Asset Management Plan, Floodplain Risk Management Plans and Coastal Management Plan. The adaptation measures could include a sea wall, sheet piles to prevent ingress, or implementing natural barriers. Noting the adverse impact of sea walls and sheet piles should be considered.	Site Wide	Engineered Solution	High	Practicality of implementation Licence requirements and planning approvals	$$$

3.5 Landfills and waste processing/resource recovery facilities

3.5.1 Landfills and waste processing/resource recovery facilities: overview

The EPA regulates disposal of waste to land (landfills), waste processing, resource recovery, and waste storage industries under the *Protection of the Environment Operations Act 1997* (PoEO Act). This sector includes the following activities:

– Resource recovery
– Waste processing (non-thermal treatment)
– Waste disposal (application to land)
– Extractive activities
– Composting
– Metallurgical activities
– Contaminated soil treatment
– Container reconditioning
– Thermal treatment of waste
– Waste disposal by application to land.

The Waste Avoidance and Resource Recovery Act 2001 (WaRR Act) complements the PoEO Act by ensuring that resource management options are considered. This Act aims to reduce environmental impact, and the EPA plays a crucial role in regulating the waste industry to ensure the compliance with these acts.

In summary, this climate adaptation measures research study identified a total of 58 adaptation measures for landfills and waste processing facilities, categorised as below:

– 6 desktop assessment
– 25 engineered solution
– 12 manuals, plans, policies, and procedure
– 1 collaboration
– 11 monitoring protocol
– 3 nature-based solutions

Table 8 provides the long list of these measures and the associated feasibility assessment[10]. Discussions with SMSs revealed that the implementation of significant measures to prevent leachate contamination and the use of coverings to prevent erosion and dust generation is already present and considered Business-As-Usual at landfill and waste processing/resource recovery facilities. However, these actions will need to be updated and adjusted to future climate changes and as environmental protection regulations evolve.

There were only 5 adaptation measures that were considered to have high effectiveness, 4 of which were ‘Engineered Solutions’, 1 of which was a ‘Desktop Solution’. These ranged from low relative cost i.e. ‘$’ to high relative cost i.e. ‘$$$’, with the high effectiveness, low-cost solutions representing low-hanging fruit that should be considered first for implementation by facilities if appropriate. Given the nature of waste processing facilities and landfills, there were also a number of nature-based solutions identified to reduce risks associated with rainfall, drought and rising sea level which should also be prioritised where possible given the co-benefits that can accompany these solutions.

[10] Note that Table 8 has not included measures that were classified as overarching and were therefore included in Table 5.

3.5.2 Landfills and waste processing/resource recovery facilities: Climate adaptation measures

Climate adaptation measures identified for the landfill and waste processing/resource recovery sector, in response to the climate change induced environmental risks (outlined in Section 3.1), have been identified in Table 8 below.

Table 8 Climate adaptation measures - Landfills and waste processing/resource recovery facilities

Adaptation measure	Asset Component	Adaptation category	Feasibility Assessment		
			Effectiveness	Barriers	Cost
Risk 01: Increased frequency, severity, and duration of extreme rainfall events leading to potential pollution of nearby waterways and/or land.					
Implement enclosed composting to shift higher-risk activities, such as primary composting, under cover. This reduces exposure to high rainfall and minimises the generation of leachate and odour emissions.	FOGO	Engineered Solution	Low	Practicality of implementation Licence requirements and planning approvals	$$$
Despite enclosed composting, outdoor maturation areas can still be affected by excessive rainfall, generating runoff with high organic content. This runoff must be collected and treated appropriately, potentially requiring disposal to sewer systems with pretreatment, as per the trade waste agreement. Stockpiles should be placed on impervious surfaces such as hardstand, geomembrane, or compacted gravel to further prevent ground contamination and aid in runoff control.	FOGO	Engineered Solution	Low	Practicality of implementation Licence requirements and planning approvals	$$$
Include requirements for regular maintenance checks of the landfill cell (including lining and capping) in both the landfill operational and closure plans. These checks should outline monitoring procedures to assess the condition of the landfill cap, particularly to detect erosion leading to potential infiltration.	Landfill cells	Manuals, Plans, Policies, and Procedures	Low	N/A	$
Implement progressive capping of the landfill - temporary capping to be provided for cells that are temporarily out of operation.	Landfill cells	Engineered Solution	Medium	N/A	$$
Enter into trade waste agreements so that leachate treated to the required water quality standards can be diverted and discharged to the sewer network during major rainfall events.	Landfill cells	Manuals, Plans, Policies, and Procedures	Medium	Stakeholder complexity Practicality of implementation	$$
Incorporate geomembranes/geotextiles for liners (for new landfills) and for landfill capping (for closed landfills), to reduce infiltration and minimise leachate production from extreme rain events. Designs should be in accordance with NSW Environmental Guidelines Solid Waste Landfills (Second edition, 2016), or the latest revision available.	Landfill cells	Engineered Solution	Medium	Practicality of implementation Licence requirements and planning approvals	$$$
Review the permeability of the existing cap design and surface water management systems to improve stormwater drainage capacity associated with increased rainfall intensity (i.e. increased volumes of rainfall). Consult the Australian Rainfall and Runoff (ARR) guidelines (ARR19v4.2 or latest revision available) to assess climate change factors in sizing of water management and containment systems.	Landfill cells	Desktop Assessment	Enabling	N/A	$
Design landfill cells in accordance with the NSW Environmental Guidelines Solid Waste Landfills (Second edition, 2016), or the latest revision available and ensure that construction	Landfill cells	Desktop Assessment	Enabling	N/A	$

Adaptation measure	Asset Component	Adaptation category	Feasibility Assessment		
			Effectiveness	Barriers	Cost
is undertaken under qualified engineering supervision and includes appropriate Construction Quality Assurance (CQA) steps and hold points.					
Review the capacity of the existing infrastructure to adequately manage flows under projected climate change conditions. The Australian Rainfall and Runoff Guideline ARR19v4.2 (or the latest revision of this guideline available) should be referenced when undertaking this assessment.	Leachate management Storage ponds Stormwater management	Desktop Assessment	Enabling	Regulation/Guideline reform Licence requirements and planning approvals	$
Assess performance of existing water management infrastructure to determine extent of required infrastructure or processing upgrades to accommodate higher rainfall events.	Leachate management Storage ponds Stormwater management	Desktop Assessment	Enabling	Regulation/Guideline reform Licence requirements and planning approvals	$
Update contingency plans to include emergency overflow solutions, such as temporary storage or controlled bypasses, to manage and mitigate risks of untreated discharges.	Leachate management Storage ponds Stormwater management	Manuals, Plans, Policies, and Procedures	Medium	*Licence requirements and planning approvals* *Practicality of implementation*	$$
Develop and implement contingency plans to manage excess leachate volumes during extreme rainfall events. This could include provisions for tankering and disposing of leachate at an industrial or Council wastewater treatment plant.	Leachate management Storage ponds Stormwater management	Manuals, Plans, Policies, and Procedures	Medium	Practicality of implementation Impacts to customers Licence requirements and planning approvals	$-$$$
Assess capacity of the leachate and stormwater (surface water) systems (pumps/pipes etc) to accommodate increased flows during large rainfall events.	Leachate management Storage ponds Stormwater management	Manuals, Plans, Policies, and Procedures	Low	N/A	$
a) Update Flood Risk Management Plans with to accommodate rainfall events associated with climate change.	Site wide	Manuals, Plans, Policies, and Procedures	Low	Licence requirements and planning approvals	$
b) Implementation of updated Flood Risk Management Plan, involving upgrading of facilities.	Site wide	Engineered Solution	Medium	Practicality of implementation Impacts to customers	$$$
Upgrade site infrastructure to capture and manage projected increases in rainfall intensity. ARR should be adopted by SQP to inform decision making.	Site wide	Engineered Solution	Medium	Practicality of implementation Impacts to customers Licence requirements and planning approvals	$$$
Monitor water quality data during environmental releases to assess system performance at these times. Identify potential areas for improvement or system upgrades based on the observed data.	Site wide	Monitoring Protocols	Low	Licence requirements and planning approvals	$$

Adaptation measure	Asset Component	Adaptation category	Feasibility Assessment		
			Effectiveness	Barriers	Cost
Contingency plans to divert waste to alternative landfills where they may not be affected by a particular rainfall event.	Site wide	Collaboration	Medium	Licence requirements and planning approvals Practicality of implementation	$$
Incorporate nature-based solutions, such as bio-swales, bio-retention basins, constructed wetlands (for treatment), and permeable surfaces, to manage stormwater volumes entering the system.	Site wide	Nature Based Solution	Medium	Practicality of implementation	$$$
Ensure that designs are in accordance with NSW Environmental Guidelines Solid Waste Landfills (Second edition, 2016), or the latest revision available, and allow for projected increases in rainfall intensities as per the ARR19 v4.2 guidelines (or latest revision available).	Site wide	Desktop Assessment	Enabling	N/A	$
Upgrade sediment and erosion controls (including ponds and adequately sized drains) to accommodate higher rainfall events associated with climate change.	Site wide	Engineered Solution	Medium	Practicality of implementation	$-$$$
Risk 02: Increased frequency and severity of drought conditions leading to adverse air quality impacts including dust and odour, and contamination.					
Implement adequate odour management methods at FOGO processing facilities. These could include odour scrubbers (wet scrubbers, biofilters, or activated carbon filters), odour masking sprays, covering of stockpiles, and enclosing stockpiles. If filters are used then maintenance of these systems must be captured within operation and management plans for the facility.	FOGO	Engineered Solution	Medium	Practicality of implementation	$$$
Close existing low lying landfills and establish new landfills on higher ground. Close and seal existing sites adequately to minimise water ingress and damage to cap, and disturbance of the waste mass.	Landfill cell	Engineered Solution	Medium	Practicality of implementation Licence requirements and planning approvals	$$$
Include requirements for regular maintenance checks of the landfill cell (including lining and capping) in both the landfill operational and closure plans. These checks should outline monitoring procedures to assess the condition of the landfill cap, particularly to detect erosion leading to potential infiltration.	Landfill cells	Manuals, Plans, Policies, and Procedures	Low	N/A	$
Ensure that the landfill closure plan includes a landscaping plan for the cap, with species selection and maintenance requirements. Avoid the use of deep-rooted plants to prevent damage to the landfill cap.	Landfill cell	Nature Based Solution	Medium	Licence requirements and planning approvals	$
Implement aerators (e.g. surface and subsurface aerators) or add chemicals to leachate ponds to prevent them going anaerobic and releasing odours.	Leachate Pond	Engineered Solution	Medium	N/A	$$
Risk 03: Increased frequency, severity, and duration of extreme rainfall or storm events leading to potential adverse odour quality impacts.					
Undertake long-term, regular maintenance checks of landfill cells (lining, capping and temporary cover) and gas extraction systems and include these requirements in maintenance manuals and aftercare management plans. Any areas of settlement should be filled in and repaired	Landfill cell	Manuals, Plans, Policies, and Procedures	Low	N/A	$
Ensure that the landfill is designed in accordance with relevant landfill design guidelines including adequate slope to enable drainage of stormwater and prevent pooling in any areas of temporary cover or final capped landfill. Stormwater allowances should take appropriate climate change scenarios into consideration.	Landfill cell	Engineered Solution	High	N/A	$

Adaptation measure	Asset Component	Adaptation category	Feasibility Assessment		
			Effectiveness	Barriers	Cost
Actively manage landfill gas systems, as any opening in the cap can lead to the release of gas. Incorporate gas monitoring into the landfill closure plan, including site overs using a gas meter, and perimeter monitoring wells if possible. This monitoring would apply to both closed landfills and areas of operational landfills that have been closed in the past.	Landfill cell	Monitoring Protocols	Medium	N/A	$$
Design redundancy into landfill gas management infrastructure where possible, so that the system does not go offline if one element is impacted.	Landfill cell	Engineered Solution	Medium	Practicality of implementation	$
Minimise the area of the landfill tipping face to reduce exposure of waste to extreme weather events.	Landfill cell	Engineered Solution	Low	N/A	$
Risk 04: Increased frequency, and severity of extreme heat and bushfires leading to fires at licenced facilities resulting in adverse air quality impacts and potential ecological destruction.					
Conduct more frequent temperature monitoring of outdoor maturation windrows and stockpiles during hotter weather.	FOGO	Monitoring Protocols	Low	N/A	$
Prepare a Fire Prevention Plan in accordance with Section 6.5 of the NSW Landfill Guidelines and Section 8 of Fire and Rescue NSW's Fire Safety in Waste Facilities guideline (or the latest revision available), which covers (at a minimum) procedures and protocols for storage of materials and emergency measures in the case of a fire.	Landfill cells	Manuals, Plans, Policies, and Procedures	Low	N/A	$
Check all incoming loads at the weighbridge to assess whether any hot waste or waste with potential to self-ignite is being disposed of.	Site wide	Monitoring Protocols	Low	N/A	$
For outdoor composting facilities, ensure that stockpiles of garden organics are processed quickly to minimise the possibility of self-ignition under extreme heat conditions.	Site wide	Manuals, Plans, Policies, and Procedures	Medium	N/A	$
Any stockpiles of processed material should be kept moist to prevent self-ignition and dust generation.	Site wide	Manuals, Plans, Policies, and Procedures	Medium	N/A	$
Include landfill gas temperature monitoring of gas wells in operational plans, to detect subsurface fires. In addition, measure carbon monoxide levels to detect any below surface fires/smouldering. Increase the frequency during periods of hotter weather.	Site wide	Monitoring Protocols	Low	N/A	$
Implement firefighting and containment methods outlined in Fire Prevention Plans, including fire suppression (potentially triggered by smoke detectors or thermal cameras), temperature monitoring sensors/mechanisms, asset protection zones, and fire tanks/pumps and hydrants (resource recovery facilities) where applicable.	Site wide	Manuals, Plans, Policies, and Procedures	Medium	N/A	$$$
If facility is located in a bushfire prone area, maintain an appropriately sized asset protection zone (APZ) around the perimeter of the site, in accordance with a Bushfire Management Plan.	Site wide	Engineered Solution	Medium	N/A	$
Risk 05: Extreme weather events (temperatures, rainfall, storms) leading to treatment facilities going offline resulting in potential odour impacts and untreated flows to the environment (water and land) or reduced air quality (odour).					
Elevating or flood proofing of critical electrical components so they aren't flooded and impact operation.	Electrical infrastructure	Engineered Solution	High	Practicality of implementation	$$$
Assess additional requirements for generators or backup power supplies onsite in the instance that power is cut to the site. Critical infrastructure should be connected to these	Site wide	Engineered Solution	High	Practicality of implementation Impact to customers	$$$

Adaptation measure	Asset Component	Adaptation category	Feasibility Assessment		
			Effectiveness	Barriers	Cost
backup supplies to avoid complete site shutdown. This will be of importance for landfill gas management and leachate management processes.					
Risk 06: Rising sea levels leading to inundation of coastal facilities resulting in potential water and land contamination					
For landfills located in low lying coastal land, consider physical defences to protect the landfill cells such as external bunds.	Landfill cell	Engineered Solution	Medium	Practicality of implementation Licence requirements and planning approvals	$$
Close existing low lying landfills and establish new landfills on higher ground. Close and seal existing sites adequately to minimise water ingress and damage to cap, and disturbance of the waste mass.	Landfill cell	Engineered Solution	Medium	Practicality of implementation Licence requirements and planning approvals	$$$
Assess and implement or enhance natural barriers such as mangroves or tidal marshes to protect from coastal inundation and storm surges.	Landfill cell	Nature Based Solution	Medium	Practicality of implementation Licence requirements and planning approvals	$$$

3.6 Intensive agriculture and livestock processing

3.6.1 Intensive agriculture and livestock processing: overview

Intensive agriculture and livestock processing focuses on the management, accommodation, and processing of various livestock, including cattle, sheep, pigs, dairy animals, and birds. The operations involved under intensive agriculture is predominantly animal accommodation, where livestock are housed and cared for. Livestock processing included slaughtering, carcass dressing, chilling, packaging, and other related operations. Intensive agriculture and livestock processing facilities also handle essential processes like meat cleaning, freezing, rendering, wastewater treatment and waste management, which are all regulated under the Protection of the Environment Operations Act 1997 (PoEO Act) to ensure environmental compliance across the two industries. EPA recognises the importance of these two industries, with animal production and the agriculture supply chain playing a vital role in food security, supporting global economies and meeting the population demand for animal-based products.

In summary, this climate adaptation measures research study identified a total of 51 adaptation measures for the intensive agriculture and livestock processing industries. The categorisation of these adaptation measures was as follows:

– 7 desktop assessments
– 30 engineered solutions
– 7 manuals, plans, policies and procedures
– 5 monitoring protocols
– 2 nature-based solutions

Table 9 provides the long list of these adaptation measures and the associated feasibility assessment[11]. As mentioned earlier there were many commonalities between the intensive agriculture and livestock processing facilities with regards to adaptation measures, which is why they have been presented together. Of the 51 adaptation measures identified, 17 related to both industries, 24 related to intensive agriculture, and 10 related to livestock processing.

As with some of the other industries, in most instances, the highly effective, ‘Engineered solutions’ were also identified as having a high cost (i.e. $$$), and the less effective, and enabling solutions such as ‘Desktop assessments’ and ‘monitoring protocols’ were associated with lower costs ($, $$).

A key finding from this study is that while the intensive agriculture and livestock processing industries are generally well-conditioned for health and safety regulations, there are areas where further adaptation measures are needed to address environmental impacts, with climate change poised to potentially overwhelm existing systems. Additionally, intensive agriculture could benefit from exploring more nature-based solutions, such as improving soil health and water management, to better integrate climate resilience and where possible maximise co-benefits.

[11] Note that Table 9 has not included measures that were classified as overarching and were therefore included in Table 5.

3.6.2 Intensive agriculture and livestock processing: Climate adaptation measures

Climate adaptation measures identified for the intensive agriculture and livestock processing industries in response to the climate change induced environmental risks (outlined in Section 3.1), have been identified in Table 9.

Table 9 Climate adaptation measures - Intensive agriculture and livestock processing

Adaptation measure	Asset Component	Adaptation category	Feasibility Assessment		
			Effectiveness	Barriers	Cost
Risk 01: Increased frequency, severity, and duration of extreme rainfall events leading to potential pollution of nearby waterways and/or land.					
Install robust drainage systems, such as ditches, channels, and swales, to direct excess water away from animal housing and prevent waterlogging. This reduces manure contamination, minimises nutrient leaching into nearby water bodies, and helps control erosion by allowing water to flow off fields efficiently.	Animal accommodation	Engineered Solution	Medium	N/A	$$
Incorporate nature-based solutions, such as constructed wetlands to manage wastewater runoff from animal housing entering natural waterways.	Animal accommodation	Nature Based Solution	Medium	Practicality of implementation	$$$
Investigate if existing animal accommodation (such as barns, stables, or feedlots) is situated a minimum distance from rivers, lakes, wetlands, or any water bodies to reduce the risk of animal waste, chemicals, and feed runoff contaminating water.	Animal accommodation	Desktop Assessment	Low	Practicality of implementation Licence requirements and planning approvals	$
Potential relocation or raising of the effluent pond to reduce likelihood of being affected by floods.	Effluent ponds	Engineered Solution	High	Regulation/Guideline reform Licence requirements and planning approvals	$$$
Designs for new drainage and water related infrastructure should take into consideration the climate change factors presented in the Australian Rainfall and Runoff Guideline ARR19v4.2 (or the latest revision of this guideline available). They should also be constructed outside of flood prone areas and have sufficient freeboard.	Effluent ponds Water storage ponds	Engineered Solution	High	Regulation/Guideline reform Licence requirements and planning approvals	$
Protecting feedlots with physical barriers to prevent rainwater or floodwater ingress. This could include covered areas. Feed material can be contaminated with pesticides which can leach into waterways.	Feed lots	Engineered Solution	Medium	N/A	$$
Implement field buffers and levees (around riparian areas) to manage, soil erosion, filter runoff and safeguard feedlots from flooding and water contamination.	Feedlots	Engineered Solution	Medium	Regulation/Guideline reform Licence requirements and planning approvals	$$
Use anaerobic digesters to manage manure storage and treatment, reducing the production of harmful gases like methane and ammonia, and preventing the spread of odours during extreme rainfall events.	Manure management	Engineered Solution	Medium	Practicality of implementation Regulation/Guideline reform Licence requirements and planning approvals	$$$
Implement impermeable flooring and effective drainage systems to direct excess water away from processing infrastructure and holding areas of livestock.	Processing areas Livestock holding areas	Engineered Solution	Medium	N/A	$$

Adaptation measure	Asset Component	Adaptation category	Feasibility Assessment		
			Effectiveness	Barriers	Cost
a) Develop a Flood Risk Management Plan to accommodate rainfall events associated with climate change.	Site wide	Manuals, Plans, Policies, and Procedures	Low	Licence requirements and planning approvals	$
b) Implementation of updated Flood Risk Management Plan, which could include upgrading of facilities and water management infrastructure. This could include relocation of critical infrastructure such as sedimentation dams that lie within a flood prone area.	Site wide	Engineered Solution	Medium	Practicality of implementation Impacts to customers	$$$
Integration of real-time automated monitoring systems and early warning systems that continuously track key parameters at discharge points, and upstream/downstream to understand the baseline conditions of the water. The trigger for alerts should be assessed	Site wide	Monitoring Protocols	Low	Practicality of implementation Licence requirements and planning approvals	$$
Implement more robust weather monitoring systems that and can trigger when significant rain events may be about to occur.	Site wide	Monitoring Protocols	Low	N/A	$$
Ensure there is backup power supply (generators) to the site to in the event of a power outage to maintain function of critical water treatment and processing infrastructure.	Site wide	Engineered Solution	Medium	Practicality of implementation	$$
If primary composting occurs on site, there is potential for high rainfall to generate excessive runoff from the high organic content. This runoff must be collected and treated, to minimise the risk of leachate formation and improve nutrient recycling.	Site wide	Engineered Solution	Low	Practicality of implementation Licence requirements and planning approvals	$$$
Existing sites should have all chemicals securely stored to avoid uncontrolled release of pollutants.	Site wide	Manuals, Plans, Policies, and Procedures	Low	Regulation/Guideline reform Licence requirements and planning approvals	$
Install permanent or temporary shaded structures to protect livestock. The shaded structures should be placed within the stocking area with additional ground cover (grass, mulch) to prevent soil erosion and water runoff.	Site wide	Engineered Solution	Medium	Regulation/Guideline reform Licence requirements and planning approvals	$$$
Implement early warning systems site wide to alert famers to move livestock to cover. This allows for proper waste management to occur preventing odour issues and minimising the impact of waste accumulating during rainfall events.	Site wide	Engineered Solution	Low	N/A	$
Risk 02: Increased frequency and severity of drought conditions leading to adverse air quality impacts.					
Assess capacity of ventilation systems. These systems should be automated to increase/decrease extraction rates as required to prevent odour build up.	Animal accommodation	Desktop Assessment	Enabling	Regulation/Guideline reform Licence requirements and planning approvals	$
Investigate if animal accommodation and feedlots have sprinklers or water troughs installed to prevent dust accumulation. This could be an area to implement extensive sprinklers or water systems for dust suppression.	Animal accommodation Feedlots	Desktop Assessment	Enabling	Practicality of implementation Licence requirements and planning approvals	$$

Adaptation measure	Asset Component	Adaptation category	Feasibility Assessment		
			Effectiveness	Barriers	Cost
Install permanent or temporary shaded structures over feedlots. The shaded structures should be placed within the stocking area with additional ground cover (grass, mulch) to prevent soil erosion and dust generation during drier periods.	Feedlots	Engineered Solution	Medium	Regulation/Guideline reform Licence requirements and planning approvals	$$
Implement composting and organic fertilisers to enhance soil fertility and organic matter. This helps soil to retain moisture and nutrient, crucial during drought periods.	Grazing fields	Engineered Solution	Low	Practicality of implementation Licence requirements and planning approvals	$$$
Increase the frequency of litter/manure changes and ensure spent litter is properly enclosed/bagged. This minimises/prevents odour and waste accumulation within enclosed structures.	Site wide	Engineered Solution	Medium	N/A	$
Implement large water tanks or reservoirs to ensure uninterrupted water supply for livestock processing, particularly for cleaning and cooling.	Site wide	Engineered Solution	Low	Practicality of implementation Licence requirements and planning approvals	$$$
Use water carts for dust suppression.	Site wide	Engineered Solution	High	Licence requirements and planning approvals	$$$
Spread manure/irrigate effluent in the afternoon, rather than in the morning when the air is still and there is little or no dispersion. The manure should be incorporated into the ground as soon as possible. This minimises odour generation and movement through hot air.	Site wide	Engineered Solution	Medium	N/A	$
Design ponds/reservoirs to store water during wet periods for use during drought periods for dust suppression.	Water storage	Engineered Solution	High	Regulation/Guideline reform Licence requirements and planning approvals	$$$
Assess capacity of onsite rainwater capture and storage. Ensure there is a reliable irrigation source to utilise during drought conditions. This will reduce the dependence on groundwater and external water sources during drought periods.	Water storage	Manuals, Plans, Policies, and Procedures	Low	Licence requirements and planning approvals	$
Risk 03: Increased frequency, severity, and duration of extreme storm events leading potential adverse odour quality impacts.					
Maintain aeration of water management lagoons to prevent still water from turning anerobic and producing odours	Effluent ponds Water storage ponds	Engineered Solution	Medium	Practicality of implementation Licence requirements and planning approvals	$$
Protect feedlots with physical barriers to prevent rainwater or floodwater ingress. This could include covered areas. Feed material can be contaminated with pesticides which can leach into waterways. They also decompose faster in wet environments which can generate odour.	Feed lots	Engineered Solution	Medium	N/A	$$
Investigate the procurement of low-odour feed i.e. feed that is less likely to produce odour when decomposing.	Feedlots	Desktop Assessment	Enabling	N/A	$
Implementation of covered or sealed manure storage systems (covered lagoons or anaerobic digesters).	Manure management	Engineered Solution	Medium	N/A	$$

Adaptation measure	Asset Component	Adaptation category	Feasibility Assessment		
			Effectiveness	Barriers	Cost
Designs for temporary or permanent flood barriers around agriculture infrastructure to protect from rising waters and storm surges.	Site wide	Engineered Solution	Medium	Practicality of implementation Regulation/Guideline reform Licence requirements and planning approvals	$$$
Integrate real-time automated monitoring systems that continuously track climate forecast to initiate farming technologies to manage overflow during extreme storm events.	Site wide	Manuals, Plans, Policies, and Procedures	Low	Licence requirements and planning approvals	$
Risk 04: Increased frequency, and severity of extreme heat and bushfires leading to fires at licenced facilities resulting in adverse air quality impacts and potential ecological destruction.					
Install air filtration and ventilation systems to manage increased ammonia and particulate matter emissions, which can intensify during high temperatures. These systems help manage the air quality and protect livestock from harmful pollutants.	Animal accommodation	Engineered Solution	Medium	Regulation/Guideline reform Licence requirements and planning approvals	$$
Install air filtration and ventilation systems to manage increased ammonia and particulate matter emissions, which can intensify during high temperatures. These systems help manage the air quality and protect livestock from harmful pollutants.	Animal accommodation	Engineered Solution	Medium	Regulation/Guideline reform	$$
Investigate if animal accommodation and feedlots have sprinklers or water troughs installed to prevent dust accumulation. This could be an area to implement extensive sprinklers or water systems for dust suppression.	Animal accommodation Feedlots	Desktop Assessment	Enabling	Practicality of implementation Licence requirements and planning approvals	$$
Incorporate closed-loop systems, such as reusing water (rainwater and greywater) for washing and cooling livestock and hygiene processes within the processing facilities.	Processing areas	Engineered Solution	Low	Regulation/Guideline reform Licence requirements and planning approvals	$$
Integrate real-time automated use of temperature and humidity sensors in key areas (meat storage rooms, refrigeration areas) to monitor and adjust cooling systems as needed.	Processing areas (refrigeration areas)	Monitoring Protocols	Medium	Licence requirements and planning approvals Practicality of implementation	$
Investigate transitioning to ammonia-based cooling systems. Ammonia-based cooling systems reduce electrical energy consumption and gas consumption, and use an environmentally benign refrigerant (albeit one that requires proper safety and risk management measures).	Processing areas (refrigeration areas)	Desktop Assessment	Enabling	Regulation/Guideline reform Licence requirements and planning approvals	$$$
Provisions to install or upgrade cooling towers for the refrigeration and air-conditioning systems, ensuring animals and processing areas remain cool.	Processing areas Animal accommodation	Engineered Solution	Medium	Regulation/Guideline reform Licence requirements and planning approvals	$$
Install permanent or temporary shaded structures over feedlots. The shaded structures should be placed within the stocking area with additional ground cover (grass, mulch) to prevent soil erosion during extreme heat periods.	Site wide	Engineered Solution	Medium	Regulation/Guideline reform Licence requirements and planning approvals	$$$
Prepare a Bushfire Management Plan for the site with appropriate asset protection zones surrounding the site and/or adequate fire breaks. The Plan should be revised and updated at appropriate intervals especially as climate conditions change in the future.	Site wide	Manuals, Plans, Policies, and Procedures	Low	N/A	$

Adaptation measure	Asset Component	Adaptation category	Feasibility Assessment		
			Effectiveness	Barriers	Cost
Investigate utilising anaerobic digesters to treat manure and reduce odour emissions. This would be effective during hot periods when manure breakdown releases higher amounts of gases. This approach would minimise potential ecological destruction and improve air quality.	Site wide	Desktop Assessment	Enabling	Regulation/Guideline reform Licence requirements and planning approvals	$$
Plant trees alongside pasture to create a balance between agricultural production and environmental protection (agroforestry). Agroforestry provides shelter for livestock, reducing heat stress and reduces bushfire risk by creating natural barriers against bushfires and by removing part of the dry, flammable vegetation at the ground level. Consider heat and drought tolerant species.	Site wide	Nature Based Solution	Low	N/A	$$
Extreme weather events (temperatures, rainfall, storms) leading to critical equipment going offline resulting in potential odour impacts, pollution to the environment (water and land) or reduced air quality (odour).					
Assess additional requirements for generators or backup power supplies onsite in the instance that power is cut to the site. Critical infrastructure including refrigeration systems should be connected to these backup supplies to avoid complete site shutdown.	Processing areas (refrigeration areas)	Engineered Solution	High	Practicality of implementation	$$$
Operational procedures should include pre-cooling of cold storage facilities ahead of predicted heatwaves. This strategy allows facilities to maintain safe internal temperatures during peak external heat or in the event of intermittent power supply.	Processing areas (refrigeration areas)	Engineered Solution	Medium	Practicality of implementation	$$
Refrigeration infrastructure located in flood-prone zones should be elevated or fitted with waterproofing barriers to prevent water ingress, electrical hazards, or contamination risks. Drainage systems should be inspected and maintained to ensure functionality during extreme rainfall.	Processing areas (refrigeration areas)	Engineered Solution	High	Practicality of implementation Regulation/Guideline reform Licence requirements and planning approvals	$$$

4. Barriers to adaptation implementation

The feasibility assessment (presented in section 3) identified a number of potential barriers that may slow or prevent the implementation of specific adaptation solutions. Table 2 lists and provides a description for each of these barriers and these have been considered specifically for each of the solutions identified. For completeness, these have been noted again below:

– Maturity of technology
– Commercial availability
– Practicality / feasibility of implementation
– Stakeholder complexity
– Impacts to customers
– Regulation / Guideline reform
– Licence requirements and planning approvals
– Behavioural change
– Resources

In addition to the above solution-specific barriers, there were a number of broader challenges identified through this study that should be noted for further consideration as the EPA strives to support its regulated industries on their climate adaptation journeys:

– Industry and consultants engaged in design work need clear guidelines and specifications, as being too vague often fails to achieve the necessary change. License requirements can sometimes reference outdated guidelines and regulations, which may no longer be relevant. Industry often aims to simply comply with the license requirements, rather than adopting what might be best in the long term, potentially leading to more stringent license conditions. The EPA's introduction of climate change assessment guidelines and potentially requiring new applicants to consider these guidelines from the application stage, demonstrates their willingness to shift the narrative.
– Cost is consistently a major concern, especially for councils that own or operate a landfill or solid waste facility, as it can impact rates and public perception. To address this, it is recommended that an adaptation pathway be developed, identifying necessary adaptations, conducting a cost-benefit analysis (CBA), and exploring funding opportunities to stage the works. This pathway would also create a strategy for implementing change and help address the practicality and feasibility barriers to implementation.
    - Building on this, sometimes the immediate cost is too high, leading to delays in adaptation or maintenance work. However, neglecting regular maintenance can result in much larger issues and higher costs in the future.

5. Conclusion and recommendations

This report presents potential climate-related risks and controls for five selected regulated industries licensed by the EPA, including mining, sewage treatment, landfills and waste processing/resource recovery facilities, intensive agriculture, and livestock processing. The report will help support the EPA's licensees in understanding potential climate-related risks and assist these industries in effectively managing their climate risk profile to minimise environmental risks or breach in licence requirements, adapt to changing climate conditions, and to embed resiliency into their design and operations. The list is not exhaustive, and the information is generic. Regulatory decisions should always be informed by relevant site-specific information.

In undertaking this review, there were some commonalities in the risks and adaptation measures:

- Sector specific adaptation measures and guidelines will support licensed industries in understanding and implementing climate resilience strategies.
- Ensuring ongoing monitoring and evaluation occurs so adaptation measures remain relevant and effective as climate conditions evolve.
- Promoting variance in adaptation measures and implementing nature-based solutions to avoid maladaptation and ensure long-term resilience.
- Industry guidance should be developed to ensure the consideration of ARR v4.2 Guidelines (or its latest revision) to improve rainfall and runoff predictions.
- Flood, bushfire and water management plans should be updated to take into consideration how climate change will influence the frequency and severity of these types of extreme weather events
- Industries that implement more stringent monitoring systems and protocols will be able to effectively respond to early warning systems and adjust to operational demands during extreme weather conditions.
- Designing industry asset infrastructure to adapt to extreme weather conditions as predicted under future climate scenarios will ensure long term sustainability of asset life and minimise environmental impact.
- Site conditions are going to change as climate risks evolve, therefore it is crucial for industries to increase routine inspections and implement more frequent maintenance checks during future construction and operational phases.

The above overarching measures need to be implemented alongside an array of sector specific adaptation measures to ensure effective management of climate risk and support long-term sustainability of the licensed industries in the face of evolving climate challenges.

By supporting its licensees to embed these adaptation measures, the EPA can help industries reduce environmental risks, maintain regulatory compliance, and enhance their resilience in the face of climate change

Appendix A List of sources reviews

Table A.1 Comprehensive list of all sources

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