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Embedding climate change risk into mine closure planning: a case study of tailings closure design at Ballarat Gold Mine

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Abstract

It is commonly accepted that climate change is a global challenge requiring a strong response led by both government and business. Rising levels of atmospheric greenhouse gases are increasing the severity and occurrence of extreme weather events such as storms and heatwaves and are accelerating rising sea levels. This changing climate will affect the infrastructure and resources sector both directly and indirectly. By building operational climate resilience today, companies can limit future liabilities, support business continuity, and improve the sustainability of communities and ecosystems.

With an increased focus on closure planning and design within the resources industry, especially in tailings management, it is important to establish a clear set of expectations early in the planning phase. Closure planning provides mines and smelters an opportunity to evaluate climate projections under different emission scenarios, identify and assess potential future climate hazards and associated risks, and modify final landform design to accommodate the identified physical climate risks. In several countries, nominally Australia, Canada and Chile, long-term assessment of tailings closure landforms is considered essential within the industry. For such assessments to be effective, long-term climate change data projections are required. By undertaking such assessments early, the closure design team can accommodate both current and forward hydrological projections as well as long-term behavioural changes of the capping material, with respect to potential changes in climate conditions such as increased temperatures and extended solar exposure.

This process has recently been successfully implemented at Ballarat Gold Mine as part of the closure and rehabilitation planning process. The results of these assessments, while being used in the design and forward planning of the closure of the tailings storage facility (TSF), have also been incorporated into the site-wide risk assessment and risk management plan.

This paper outlines the climate change risk assessment process undertaken for the Ballarat Gold Mine TSF, specifically the considerations, procedures and outcomes of the assessment. It furthermore describes how these prompted a re-evaluation of the final TSF design to enable it to withstand projected extreme climate events.

Keywords: *climate change risk, climate resilience, tailings closure design, final landform design, Ballarat Gold Mine*

1 Introduction

The presence of approximately 80,000 inactive and unused mine sites across Australia that pose significant long-term environmental or public health risks (Monash University 2020) is evidence that mine closure has historically not been well planned or implemented. While stakeholder expectations and regulatory requirements for mine closure and rehabilitation have grown in recent decades, requirements to address the impacts of long-term climate change in mine closure planning are yet to be regulated. Failure to address climate change physical risks in mine closure planning is failure to adequately plan for closure in a changing climate. This paper will discuss the importance of embedding climate change risk and resilience in mine closure planning. A case study will be presented to highlight how including a climate change risk scan in the mine closure process for Ballarat Gold Mine informed and prompted amendments to final landform design of the tailings storage facility (TSF) to increase resilience to a future climate of more extremes.

1.1 Importance of embedding climate change risk and resilience in mine closure planning

Climate change is a critical global challenge and is a substantial risk to both the operation and closure of mines, impacting mines directly (e.g. damage to fixed assets) and indirectly (e.g. disruption of supply chains). The International Council on Mining and Metals' Adapting to a Changing Climate: Building Resilience in the Mining and Metals Industry (International Council on Mining & Metals 2019) states that closure and post-closure are key areas of climate risk, and that climate change has the potential to increase provisioning costs and affect valuations, including for pre-closure, closure execution, post-closure and indirect closure activities (e.g. licensing costs). One of the most significant physical climate change risks to successful mine closure is the impact on the ongoing structural performance and integrity of facilities that have long life spans, such as tailings, water and waste rock storage facilities. The requirement to use climate change knowledge throughout the tailings facility lifecycle in accordance with the principles of adaptive management is addressed in the Global Industry Standard on Tailings Management (Global Tailings Review 2020).

Failure to consider climate change risks in mine closure planning can have significant financial and legal consequences, in addition to serious social and environmental implications. Climate change risks associated with mine closure can exceed those associated with operational activities due to the extended time frame of the potential impact. For a TSF, the consequences of not embedding climate risk into closure design may include increased erosion and loss of material from the cover, exceeding industry-accepted (volume per year) erosion. This may result in potential exposure of tailings at a rate faster than anticipated if historical weather data is used within the landform evolution model. If a tailings embankment is impacted by an extreme weather event, which is projected to become more commonplace as a result of climate change, the embankment may become compromised, and tailings may enter the surrounding environment. Such an event could also expose any potentially acid forming tailings to oxidation and subsequently release acid mine drainage, compounding environmental harm.

Conversely, embedding climate change risk into mine closure planning enables final landforms to be designed to be more resilient to projected climatic conditions, which may be more extreme than historical weather patterns.

2 Methodology

2.1 Climate change context

To understand the risks posed to the closure and rehabilitation of Ballarat Gold Mine from a changing climate, it is necessary to define how the climate is changing and is likely to change in the future. According to Victorian Climate Projections 2019 (State Government of Victoria & CSIRO 2019), Victoria's climate has been warming, with a mean annual temperature rise of just over 1°C between 1910 and 2018. Victoria's climate is shaped by weather systems and large-scale climate drivers that vary over space and time. This natural variability is now occurring against the backdrop of global climate change, and the climate of Victoria is changing as a result.

2.1.1 Climate variable definition

The climate variables considered in the climate change risk assessment for Ballarat Gold Mine included:

- **Rainfall,** including flooding from extreme events, and drought.
- **Temperature,** including extreme events, changes in solar radiation and evaporation rates.
- **Wind,** including storms, cyclones, and extreme wind events.
- **Soil variables,** including changes in salinity and soil stability.
- **Bushfires.**

These variables were used to provide an estimation of the likelihood of the climate-induced risks to rehabilitation processes and landform stability at Ballarat Gold Mine. Impacts associated with sea-level rise were not considered due to the mine's location being approximately 100 km northwest of Port Phillip Bay and approximately 440 m above sea level.

Historic climate data and climate projection data to identify climate change risks were sourced from the following references:

- CSIRO and Bureau of Meteorology (BOM) 2015, Climate Change in Australia Projections Cluster Report – Southern Slopes (CSIRO & BOM 2015a).
- Climate Change in Australia Summary Data Explorer (CSIRO & BOM 2015b).
- BOM (2005), Ballarat 1986–2005 weather data.
- State of NSW and Department of Environment, Climate Change and Water (2010), *Impacts of Climate Change on Natural Hazards Profile*.

2.1.2 Emissions scenario and time-slice definition

The Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report, AR5 (Intergovernmental Panel on Climate Change 2014) developed four scenarios for global climate projections that relate to how the world may respond to the challenge of a changing climate, the need to continue to produce and use energy and resources, and the global greenhouse gas emissions that may occur. These scenarios incorporate diverging tendencies based on alternative economic, globalisation and environmental pathways. These have been modified through subsequent reports and renamed as Representative Concentration Pathways (RCPs) in AR5. While from 2014, AR5 is the most current global compilation of updated climate science and projections. The IPCC is currently in its sixth assessment cycle, which is expected to be complete in 2022.

The CSIRO and BOM released the Climate Change in Australia Technical Report in 2015 (CSIRO & BOM 2015c), which links strongly to the findings of the IPCC Fifth Assessment Report, and updates the projections previously outlined in the 2007 Technical Report. The 2015 Technical Report uses over 40 global climate models to produce climate change projections as they relate to the IPCC RCP scenarios.

These RCPs are described according to levels of atmospheric concentration of CO_2 in parts per million (ppm) and may also be described by anomalies in global mean surface air temperatures for the period 2081–2100, relative to the average period 1986–2005 (Table 1).

Table 1 Climate change emission scenarios

RCP scenario	Global climate response	Projected increase in global surface temperature by 2081–2100
RCP 2.6, atmospheric concentration of CO_2 projected at approx. 420 ppm by 2100	**Strong immediate response, emissions peak by 2020**, with rapid decline in emissions thereafter from global participation and application of technologies	Mean projected increase **1.0°C** Anomaly range +0.3 to 1.7°C
RCP 4.5, atmospheric concentration of CO_2 projected at approx. 540 ppm by 2100	**Slower response, emissions peak around 2040**, then decline	Mean projected increase **1.8°C** Anomaly range +1.1 to 2.6°C
RCP 6.0, atmospheric concentration of CO_2 projected at approx. 660 ppm by 2100	**Slow response**, application of mitigation strategies and technologies	Mean projected increase **2.2°C** Anomaly range +1.4 to 3.1°C
RCP 8.5, atmospheric concentration of CO_2 projected at approx. 940 ppm by 2100 and continuing to increase	**Little curbing of emissions**, continuing rapid rise throughout the 21st century	Mean projected increase **3.7°C** Anomaly range +2.6 to 4.8°C

Current atmospheric concentration of CO_2 as of September 2022 is at approximately 420 ppm, up from being stable at about 280 ppm prior to the industrial revolution and increasing by approximately 2.5 ppm per year (National Oceanic and Atmospheric Administration 2022). Global mean atmospheric temperatures have increased approximately 1.1 degrees Celsius (°C) compared to pre-industrial levels (NASA 2022), and Australia's climate has warmed in both surface air and surrounding sea surface temperatures by around 1.44°C since 1910 (CSIRO & BOM 2020).

The climate change risk scan undertaken for Ballarat Gold Mine considered two climate change scenarios: a near-term extreme scenario (2030, RCP 8.5), and a long-term extreme scenario (2090, RCP 8.5). These time periods have relevance to both current and new infrastructure assets, depending on their design life. This allowed a narrower focus for assessment and validation at two time slices, with the use of the 2030 scenario indicating the near-term reality of climate change. The main reason for adopting the 2090 projection was to provide some perspective on the more extreme climate changes that may arise in the coming decades. The projections for these time extents may indeed arise much earlier or later than indicated, if at all; such is the uncertainty associated with the climate modelling and international responses to climate change. Projections for 2030 and 2090 are also more robust than other time periods as these variables are reported for the Southern Slopes Cluster by CSIRO, which provides greater specificity.

2.2 Climate risk scan to inform mine closure risk assessment

A climate risk scan was conducted for the Ballarat Gold Mine to identify physical risks to closure and rehabilitation of the site from the projected effects of climate change. The objective of the scan was to identify risks to mine closure from the physical effects of climate change and to understand the necessity of conducting a full climate change risk assessment.

This climate risk scan was performed using a customised framework adapted from Australian Standard *AS 5334:2013 Climate Change Adaptation for Settlements and Infrastructure – A Risk-Based Approach* (Standards Australia 2013), which is based on the risk management process given in AS/NZS ISO31000:2018 (International Organization for Standardization 2018). This screening process provided a high-level assessment of the inherent vulnerability of the site to the physical effects of climate change and was intended to briefly establish the context for the risk assessment and conduct broad identification and assessment of physical risks. The scan was executed via a review of asset design information, historical records of extreme weather events in the vicinity of the site, and climate projection data.

The screening process was intended to identify general areas of vulnerability and indicate whether a more detailed climate change risk assessment was necessary, as per Section 17 (3) of the *Climate Change Act 2017* (State Government of Victoria 2017). Findings from the climate risk scan were used to inform the risk assessment for the Ballarat Gold Mine closure and rehabilitation plan using the methodology shown in Figure 1.

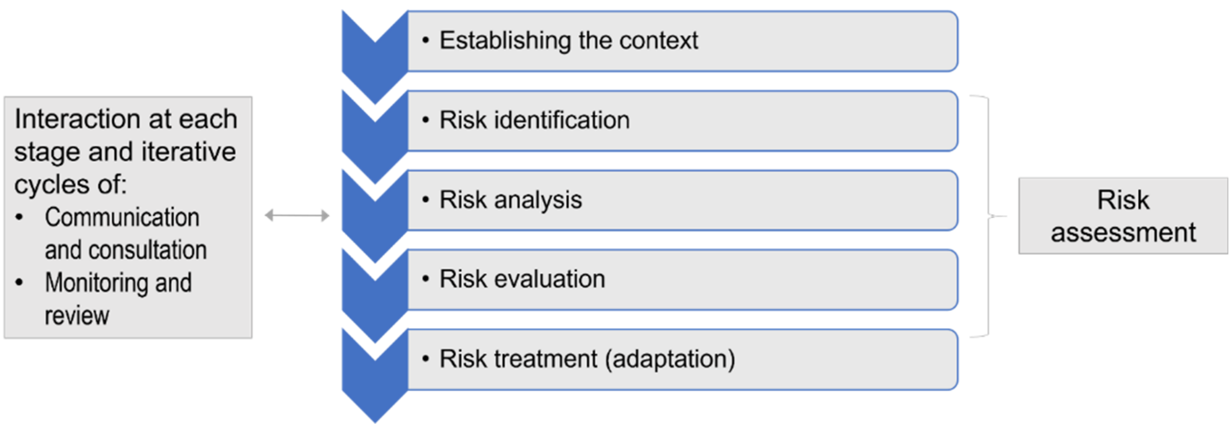

Figure 1 Climate change risk management process (adapted from AS 5334:2013, Standards Australia 2013)

2.3 Closure planning process at Ballarat Gold Mine

Closure planning at the mine has been separated out into two distinct pieces: TSF Closure Design and Planning, and Rehabilitation Planning. The TSF Closure Design and Planning clearly outlines the closure design for the TSF and the surrounding critical infrastructure, including water management and other associated infrastructure. The TSF Closure Design and Planning also sets out the following information:

- The critical risks associated with closing the facility.
- The construction and requirements for the closure of the facility.
- The ongoing management requirements for surveillance and maintenance of the TSF.
- Forward works plan detailing the next stages of work and when the works are meant to be undertaken.

The outputs from the TSF Closure Design and Planning were used to inform the Site Rehabilitation Plan, which outlines the rehabilitation requirements for the entire site.

3 Data

3.1 Climate projection data

Both quantitative and qualitative data were gathered to inform the climate risk scan in line with AS 5334:2013 (Standards Australia 2013).

3.1.1 Qualitative projections

A descriptive picture of the future climate is helpful for those assessing climate risk to consider the broad differences between current conditions and what is projected to occur under a climate projection scenario of little or insufficient global response to mitigate climate change.

The key messages from the Southern Slopes Victoria West subcluster as presented in CSIRO's Climate Change in Australia cluster projection summary tool (CSIRO & BOM 2015) are:

- Average temperatures will continue to increase in all seasons (*very high confidence).*
- More hot days and warm spells are projected to increase with *very high confidence*. Fewer frosts are projected with *high confidence.*
- Generally, less rainfall in winter and spring is projected with *high confidence*. Changes to summer and autumn rainfall are possible but less clear.

Increased intensity of extreme rainfall events is projected, with *high confidence.*

- A harsher fire-weather climate in the future is projected, with *high confidence.*
- On an annual and decadal basis, natural variability in the climate system can act to either mask or enhance any long-term human-induced trend, particularly in the next 20 years and for rainfall.

3.1.2 Quantitative projections

Of particular note for the climate risk scan performed are the following data in those projections:

- **Significant projected increase in heat stress across the site:**
  - Under the high emission scenario, the temperature at Ballarat is projected to warm on average by 0.6–1.2°C by 2030 and 2.5–4.3°C by 2090.

  - Projections show that by 2090, under the high emission scenario, the one-in-20-year hottest summer day is likely to increase by a median value of 4.1°C (to 46.1°C) compared to the 1986–2005 average.
  - A projected increase in the average number of days per year over 35°C from a baseline of 3.3 days to 5.1 days (2030) and 13.5 days (2090).
  - A projected increase in the average number of days per year over 40°C from a baseline of 0.2 days to 1.7 days (2090).
- **Significant projected increase of rainfall intensity across the site:**
  - A warmer climate is expected to bring an increase in heavy rainfall events, but variability in high rainfall events is large (+11.5–39.3% by 2090), so there is a large range of possibilities in any 20-year period.
  - The highest daily rainfall event is projected to increase from a baseline of 88.8 mm to 94.3 mm (2030) and 105 mm (2090).
  - The maximum one-day rainfall for a 20-year average recurrence interval (ARI) event increasing by 5.2% (2030) and 25.1% (2090).
- **Significant reduction in overall rainfall, soil moisture and an increase in bushfire risk:**
  - Average annual rainfall is likely to decline under the high emission scenario for the 2030 and 2090 scenarios. Average rainfall is predicted to decrease in every season, with the greatest drying in spring (14% reduction in 1986–2005 spring rainfall levels by 2090). An increase in the number of extreme heat days compounded with a decrease in average annual rainfall will lead to an increase in drought conditions.
  - Evapotranspiration is predicted to increase by +14.4% and soil moisture decrease on average by 6.8% (2090).
  - Fire danger days are subsequently expected to increase from 2.7 days (current) to 3.7–5.8 days (2090) in the Ballarat Region.

4 Results

The climate risk scan highlighted several potential key risks to successful closure and rehabilitation of Ballarat Gold Mine. Table 2 summarises key climate change risks and impacts for the mine that required a design response.

During the climate risk scan process, it became apparent that the highest climate-related risks to the successful closure and rehabilitation of Ballarat Gold Mine were associated with intense rainfall events post-closure leading to TSF spillage and/or failure of the embankment releasing tailings or diluted decant water from the TSF into the receiving environment.

The results of the climate risk scan have had a significant impact on the TSF design. Based on the risk screening, the overall reduction in rainfall, increase in evapotranspiration, and increase in rainfall intensity have a significant positive impact on the TSF. Traditionally, the design of infrastructure, whether it be mining or civil infrastructure, is based on hydrological assessments undertaken using historical data. However, with improvements in rainfall monitoring and increased data available, the industry has seen significant shifts in the quantum of rainfall runoff and hydrological impacts, to the point where previously compliant designs are no longer considered compliant as a result of the aforementioned changes. These impacts raise an important point for current engineers to consider: with a changing climate, how do we ensure designs are able to accommodate a longer design life when climate targets are expected to shift? This issue is no more present than in the design of mine closure structures where we have a goal of designing a structure capable of meeting a 1,000-year design life.

Table 2 Key climate change hazards and impacts for Ballarat Gold Mine tailings storage facility

Climate hazard	Potential impacts	Design response considerations
Severe storms	Flooding of Central Highlands Water Treatment Plant and/or Yarrowee River due to TSF spillage from a probable maximum flood (PMF) event, significantly impacting waste water treatment at the site and release of diluted decant water from the TSF.	Final landform design of the TSF, stockpiles and waste rock dump to consider a likely increase in intensity and frequency of severe precipitation events (storms, rain, hailstorms) and higher volumes of water shedding off these structures during storm events.
Earth movement	TSF3 is at full capacity and failure of embankment occurs immediately following (and as a result of) a PMF rainfall event, significantly impacting waste water treatment at the site and release of tailings into the downstream receiving environment, impacting public infrastructure, surface water and downstream ecosystems.	Final landform design of the TSF, stockpiles and waste rock dump to consider the increased risk of earth movement as a direct result of the increased intensity and frequency of severe precipitation events and higher volumes of water shedding off these structures during storm events.
Maximum temperatures, heatwaves, drought	Dust emissions from TSF and North Stockpile placement, operation and closure that cause a loss of amenity and/or exceedance above criteria. Failure of rehabilitation efforts.	Rehabilitation seeding efforts to consider predicted higher temperatures, drier soil profiles and increased evapotranspiration. Drought-tolerant native species to be considered for non-plantation areas.

For Ballarat Gold Mine, completion of a high-level climate change risk scan provided vital information of how the changing parameters, as noted above, are likely to shift the TSF design both in how it is designed and constructed but also to key rehabilitation requirements. These changes include the following:

- The decreased overall rainfall results in a need for high drought tolerance vegetation being used within the rehabilitation design, with a preference for local, native species.
- The increase in rainfall intensity requires an assessment of existing water management infrastructure but may also result in a change in methodology of the capping, specifically utilising a 'store-and-release' cover to reduce runoff erosion while capturing sufficient water for use around the site during droughts.

While the design is yet to be finalised, identification of the reduction in rainfall, increase in evapotranspiration, and increased rainfall intensity is expected to result in a change to the capping system entirely. By altering the capping system from a water-shedding facility to a store-and-release facility, runoff and erosion resulting from extreme events are expected to be reduced, thereby resulting in a far more resilient structure. These changes are also expected to result in a need to address changes to existing infrastructure, such as cut-off drainage and sedimentation ponds.

These changes may seem large looking at the problem from a current perspective; however, the long-term economic and environmental benefits of undertaking this work during the initial stages of design and operation are significant and limit the potential for costly future closure upgrade and rehabilitation works. Employment of a climate change risk assessment early in the mine closure planning process may seem heavy handed due to uncertainties associated with climate projection models; however, it can be argued that using weather data captured over the past 100 years is fundamentally deficient given our climate has changed and will continue to change.

5 Conclusion

Climate change is no longer a future prediction; our climate is changing now. Climate change is a substantial risk to successful mine closure, particularly for facilities that have long life spans, such as tailings, water and waste rock storage facilities. Embedding climate change risk assessments into mine closure planning, particularly at the initiation of any landform design, will ensure resilience of closure designs to the projected extremes of a changing climate.

Using a climate change risk scan to inform mine closure requirements at Ballarat Gold Mine, it was acknowledged that there is a step change required when determining what data is required, and this should be considered as a critical step within the development of the basis of design. By undertaking climate change risk assessments in mine closure, even at a screening level, prior to implementing long-term studies such as life-of-mine assessments and closure and rehabilitation planning, critical infrastructure will be more resilient to withstand the physical impacts from a changing climate.

The authors recommend that the resources industry continue to embed climate change risk into operational processes and mine closure planning, whether it be through an assessment of the climate risk and resilience of current infrastructure or incorporation of this process into future designs and mine closure plans. Implementation is expected to result in increased certainty in capital spending, reducing the need for costly rework and improving the stability and performance of long-term structures.

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