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Evaluating saturated water covers for limiting oxidation of tailings: a 25-year case study from Mount Lyell mine

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Abstract

The Mount Lyell copper mine in Queenstown, Tasmania, is one of Australia's oldest mining operations and has a long legacy of mine waste discharge to the Queen River. For more than 75 years, multiple waste streams were released, including an estimated 97.4 Mt of tailings and large volumes of acid and metalliferous drainage pumped from underground workings (mainly from run-off from legacy waste dumps). Riverine tailings disposal ceased in 1994, after which Copper Mines of Tasmania constructed the Princess Creek tailings storage facility (PCTSF).

The PCTSF contains approximately 42.2 Mt of potentially acid-forming tailings and mine mud, and has been raised through 6 consecutive lifts to a height of 52 m. Mining and processing operations at Mount Lyell mine ceased in 2014, when the mine was placed in care and maintenance, significantly reducing the availability of neutralisation inputs previously provided by the processing plant. In the subsequent care and maintenance period, substantial efforts were directed towards limiting oxidation of tailings by increasing tailings saturation. This involved dredging exposed tailings beaches and depositing the tailings below the decant pond level, ultimately achieving a water cover depth of greater than 10 m at the dam wall.

A unique 25-year water-quality dataset was reviewed to assess the effectiveness of saturated water covers in limiting oxidation of tailings. The dataset spans both operational conditions, which include beached tailings and ongoing neutralisation inputs, and care and maintenance conditions, during which no active tailings deposition occurred. The results demonstrate that, in the absence of additional neutralisation, saturation of previously beached tailings is associated with measurable improvements in downstream water quality (i.e. total suspended solids, sulphate, copper, lead and zinc). These findings highlight the importance of water cover management as a mine closure strategy for active and legacy TSFs in wet climates. In addition, these data provide insight into the performance of the PCTSF for mine closure planning.

Keywords: *tailings, tailing storage facility, saturated water cover, water quality, performance*

1 Introduction

Management of sulphide-bearing tailings is a key challenge for mine closure, particularly at sites with historical legacies of acid and metalliferous drainage (AMD). Water covers are widely recognised as an effective control for limiting oxidation; however, relatively few datasets demonstrate their long-term performance across operational and closure-analogue conditions (Brett 2009; International Network for Acid Prevention [INAP] 2009; Kauppila & Räisänen 2015).

The Mount Lyell copper mine in western Tasmania represents one of Australia's most enduring mining legacies, with more than a century of mining activity and extensive historical mine waste discharge to the Queen River catchment. Following cessation of riverine disposal in 1994, tailings have been stored within the

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Princess Creek tailings storage facility (PCTSF). Since the transition to care and maintenance in 2014, tailings management at the PCTSF has increasingly relied on maximising saturation through sustained water covers.

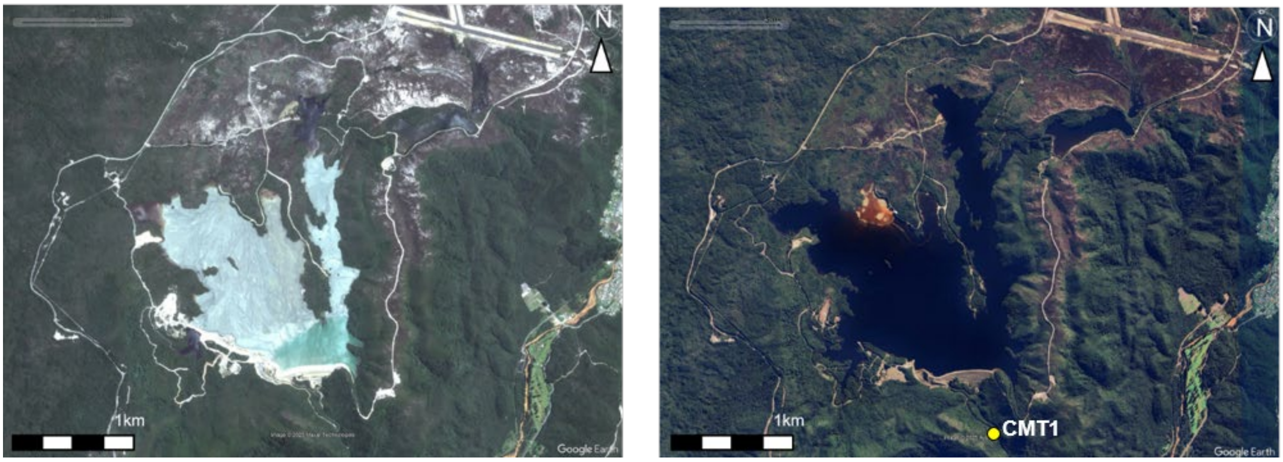
This paper presents a 25-year case study integrating tailings geochemistry, mineralogy and downstream water quality monitoring to evaluate the effectiveness of saturated water covers in limiting oxidation of reactive tailings. The objective is to assess the implications of water cover management for mine closure planning, with particular relevance to wet climatic settings and legacy tailings facilities.

1.1 Site and tailings facility overview

The Mount Lyell mining field has been active since the late 19th century, with large-scale operations commencing in the early 1900s. Between 1916 and 1994 an estimated 97.4 Mt of pyritic tailings and large volumes of AMD from underground workings and exposed waste rock dumps were discharged directly to the Queen River system. Construction of the PCTSF commenced in 1995 to contain ongoing tailings production.

The PCTSF has received approximately 42.2 Mt of tailings and mine mud and has been raised through 6 staged lifts to a crest height of approximately 52 m. Tailings are derived from copper sulphide ores and are pyritic in nature. Mining and processing ceased in January 2014, and the site entered care and maintenance later that year.

During operations, alkalinity was added to the PCTSF via the process plant and co-deposited with tailings, acting as a co-treatment mechanism for AMD and lime was added directly to the PCTSF itself. During operation the mine met its treatment obligations by directing mine mud to the TSF. Following the closure of the concentrator, alkalinity inputs declined significantly. Management actions undertaken between 2014 and 2015 focused on limiting tailings oxidation by dredging exposed tailings beaches and relocating tailings below the decant pond level, establishing widespread saturation and water cover depths typically greater than 1 m. The difference in saturation levels pre- and post-water level increase is compared in Figure 1.



(a) (b)

Figure 1 Princess Creek tailings storage facility: (a) Example of saturation conditions in January 2012; (b) Example of saturation conditions in April 2023 (Images from Google Earth 2025)

2 Tailings geochemistry and oxidation mechanisms

2.1 Tailings behaviour under unsaturated conditions

Static and kinetic geochemical testing consistently classifies PCTSF tailings as potentially acid forming (PAF) (GHD 2013, 2014; van Balen 2019). Acid base accounting results demonstrated limited buffering capacity and high maximum potential acidity across the varying water cover depths when samples were taken prior to complete saturation (Table 1). Kinetic testing indicated rapid oxidation underexposed conditions, with acidic drainage (pH < 4) developing within months rather than years (GHD 2013, 2014).

Table 1 Princess Creek tailings storage facility tailings mineralogy and geochemistry summarised from van Balen (2019) (NAG, net acid generation; NAPP, net acid producing potential; SAI, sulphide alteration index; kg H_2SO_4/t, kilo grams of sulfuric acid per tonne; EAF, extremely acid forming; AF, acid forming; PAF, potentially acid forming).

Properties	Unit	Oxidised zone (exposed tailings)	Transitional zone	Fresh zone (saturated tailings)
Bulk mineralogy	–	Barite, chalcopyrite, chlorite, goethite, hematite, magnetite, quartz, pyrite, muscovite	Quartz, pyrite, chlorite, albite, magnetite, chalcopyrite, muscovite	Quartz, pyrite, chlorite, albite, magnetite, chalcopyrite, muscovite, barite
NAG pH	pH unit	2	2	2.1
Paste pH	pH unit	4.2	7.2	7.4
NAPP	kg H_2SO_4/t	272	211	168
Geoenvironmental risk	–	EAF/AF	AF/PAF	PAF
Pyrite content	wt %	3.8	8.3	7.6
Secondary oxides	wt %	2.2	1.9	1.7
Amorphous content	wt %	43.7	2.6	6.3
SAI	–	5/10	4.2/10	3.6/10
Total sulphur	wt %	8.9	5.6	5.5
Total carbon	wt %	0.1	0.1	0.2
Sulphide preservation	–	Poor	Moderate to poor	Good

Field observations during operations and studies showed widespread oxidation of beached tailings, including desiccation cracking, formation of secondary iron oxides and low-pH pore waters (van Balen 2019; GHD 2013). Reclassification of historic datasets using contemporary AMD frameworks confirmed that oxidised surface tailings posed a high risk of acid generation and metal leaching.

Oxidation is interpreted to occur via a combination of oxygen-driven and ferric iron-mediated reactions, with ferric iron oxidation accelerating sulphide breakdown under acidic conditions (Nordstrom & Alpers 1997; St-Arnaud 1994). These mechanisms result in increasing metal concentrations and declining pH in downstream waters during periods of prolonged tailings exposure.

2.2 Tailings behaviour under saturated conditions

In contrast, mineralogical and geochemical investigations undertaken during care and maintenance revealed markedly different behaviour beneath sustained water covers. Core sampling across the PCTSF defined 3 broad zones: oxidised, transitional and fresh tailings.

Tailings beneath the water cover exhibited minimal oxidation, good sulphide preservation and limited secondary oxide formation, despite retaining a PAF classification (Table 1). Oxidation was largely confined to thin horizons interpreted as periods of temporary exposure during deposition (van Balen 2019). Mineralogical indices confirmed improved sulphide preservation with increasing water depth, highlighting the importance of sufficient depth to limit oxygen ingress and wind-driven reoxygenation.

These observations confirm that saturation significantly suppresses oxidation kinetics, even where intrinsic acid-forming potential remains high, which is consistent with other observations (i.e. Tremblay & Hogan 2001; INAP 2009).

3 Long-term water quality response

3.1 Monitoring approach

Water quality on site has been monitored since the late 1990s. A dataset that includes the water quality results from June 1998 to September 2024 was evaluated and compared to Environmental Protection Notice (EPN) quality guidelines. Location known as CMT1 (shown in Figure 1), downstream of the PCTSF, reflects discharge from the PCTSF and dam toe seepage, particularly during low flow conditions, and provides a continuous record of environmental performance under both operational and care and maintenance conditions.

The Copper Mines of Tasmania Pty Ltd (Agreement) Act 1999 (Tasmanian Government, 1999) and EPN 308/2 sets investigation trigger levels and discharge limits for water discharging to the environment. Water monitoring locations directly related to the PCTSF are PCDS and CMT1. Water is discharaged into the Princess Creek from CMT1 and is therefore subject to discharge limits shown inTable 2. There are also EPN investigation trigger levels set for CMT1 (Table 3). If the concentrations exceed these levels, an investigation into the possible cause of the exceedence must be conducted.

Table 2 Environmental Protection Notice discharge limits at CMT1

Parameters	Unit of measurement	Maximum limits
Total suspended solids	mg/L	50
Copper (total)	mg/L	0.1
Lead (total)	mg/L	0.01
Zinc (total)	mg/L	0.2
Fluoride	mg/L	2.0
Total petroleum hydrocarbons	mg/L	0.5

Table 3 Environmental Protection Notice investigation of trigger levels at CMT1

Parameters	Unit of measurement	Maximum limits
pH	pH unit	Not less than 5.9
Total suspended solids	mg/L	20
Copper (total)	mg/L	0.04
Iron (total)	mg/L	2.0
Lead (total)	mg/L	0.005
Zinc (total)	mg/L	0.1
Manganese (total)	mg/L	1.8
Sulphate (SO_4)	mg/L	400
Fluoride	mg/L	1.5

3.2 Operational conditions with a tailings beach versus saturated conditions

During active mining (1998–2014), water quality at CMT1 frequently exceeded investigation trigger levels and discharge limits for copper, lead, zinc, iron, and total suspended solids (TSS, e.g. Figures 2 to 6).

These exceedances coincided with periods of reduced alkalinity addition, extended exposure of tailings beaches and declining pH within the PCTSF.

Following establishment of sustained tailings saturation, water quality improved markedly. From approximately 2016 onwards, exceedances of regulatory thresholds for copper, lead, zinc, sulphate and TSS decreased substantially, despite minimal ongoing alkalinity input (Figures 2 to 6). Summary statistics of the findings are as follows (and presented in Table 4):

- Copper exceeds the investigation trigger (n = 208) and discharge limit (n = 58) over the monitoring period. Exceedances are markedly lower during care and maintenance compared to operation, with investigation-level exceedances decreasing from 29 to 5% of samples and discharge-level exceedances from 8.3 to 1.3%. Note that some copper discharge has previously been attributed to material within the TSF wall and subsequent oxidation and leaching of this.
- Lead exceeds both the investigation trigger (n = 588) and discharge limit (n = 128) over the monitoring period. Exceedances are substantially higher during operation than care and maintenance, with 61 versus 7.5% of samples exceeding the investigation trigger and 14 versus 0.9% exceeding the discharge limit. From February 2019 onwards, lead concentrations during care and maintenance generally remain below discharge limits.
- Zinc exceeds both the investigation trigger (n = 59) and discharge limit (n = 30) over the monitoring period. Investigation-level exceedances are lower during care and maintenance than operation (1.6 versus. 5.6 of samples), whereas discharge-level exceedances are slightly higher during care and maintenance (4.8 versus 0.3%). The highest zinc concentrations during the time series occurred in 2024 under care and maintenance conditions, reaching a maximum of 5.5 mg/L.
- No EPN discharge limit is set for sulphate; however, sulphate at CMT1 exceeds the investigation trigger (n = 70) over the monitoring period. Exceedances are markedly lower during care and maintenance compared to operation, with investigation-level exceedances declining from 8% of samples to 0.2% (one sample).
- TSS exceed both the investigation trigger (n = 181) and discharge limit (n = 63) over the monitoring period. Exceedances are substantially lower during care and maintenance than operation, with investigation-level exceedances decreasing from 20 to 2.5% of samples and discharge-level exceedances from 7.2 to 0.4%. Apart from 2 measurements (0.4%), TSS concentrations during care and maintenance remain below the EPN discharge limit.

Table 4 Sumamry statistic of water performance at CMT1

Parameters	Data range	Environmental protection notice	Number of data	Percentage of data
Copper	Operation (n=622)	Investigation Trigger (0.04 mg/L)	181	29%
		Discharge limit (0.1 mg/L)	51	8.20%
	Care and maintenance (n=560)	Investigation Trigger (0.04 mg/L)	27	4.80%
		Discharge limit (0.1 mg/L)	7	1.30%
Lead	Operation (n=896)	Investigation Trigger (0.005 mg/L)	546	61%
		Discharge limit (0.01 mg/L)	123	14%
	Care and maintenance (n=560)	Investigation Trigger (0.005 mg/L)	42	7.50%
		Discharge limit (0.01 mg/L)	5	0.90%
Zinc	Operation (n=888)	Investigation Trigger (0.1 mg/L)	50	5.60%
		Discharge limit (0.2 mg/L)	3	0.30%
	Care and maintenance (n=560)	Investigation Trigger (0.1 mg/L)	9	1.60%
		Discharge limit (0.2 mg/L)	1	0.20%
Total suspended solids	Operation (n=850)	Investigation Trigger (20 mg/L)	167	20%
		Discharge limit (50 mg/L)	61	7.20%
	Care and maintenance (n=560)	Investigation Trigger (20 mg/L)	14	2.50%
		Discharge limit (50 mg/L)	2	0.40%
Sulphate	Operation (n=829)	Investigation Trigger (400 mg/L)	69	8%
	Care and maintenance (n=566)	Investigation Trigger (400 mg/L)	1	0.20%

Concentrations of key metals remained generally below discharge limits, indicating limited ongoing oxidation of sulphide minerals. Iron and manganese occasionally exceeded investigation triggers during low flow periods, which were interpreted as reflecting localised seepage and reduced dilution rather than renewed widespread tailings oxidation. The observed reduction in TSS concentrations is likely attributable to the establishment of a deeper water cover, which submerged previously exposed tailings beaches, reduced wind- and run-off-induced sediment mobilisation, and increased the separation between the tailings surface and the water column, thereby limiting particle resuspension and promoting settling of fine-grained material. Overall, the long-term dataset demonstrates a clear improvement in water quality associated with saturation of previously exposed tailings.

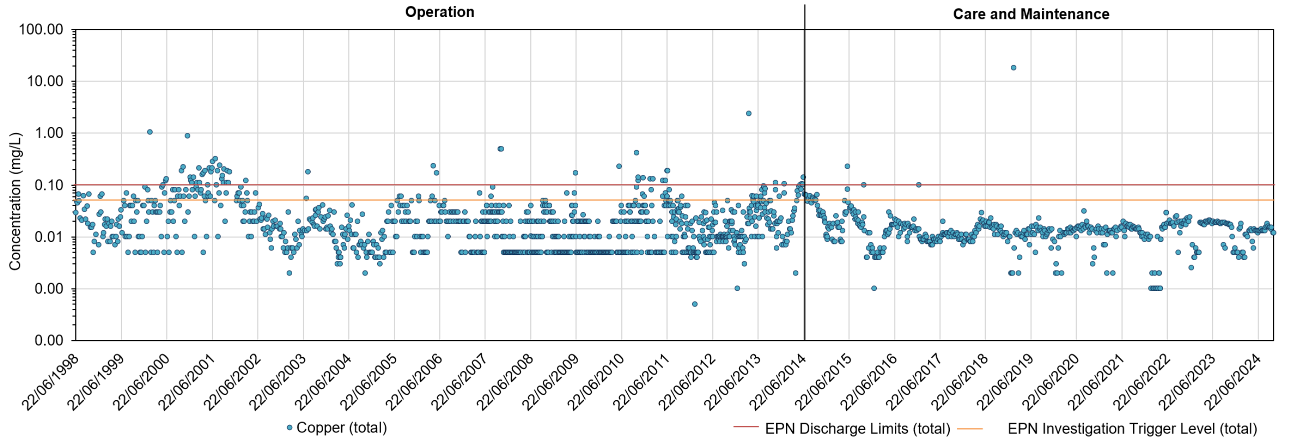


Figure 2 Copper concentrations at CMT1 (EPN = Environmental protection notice)

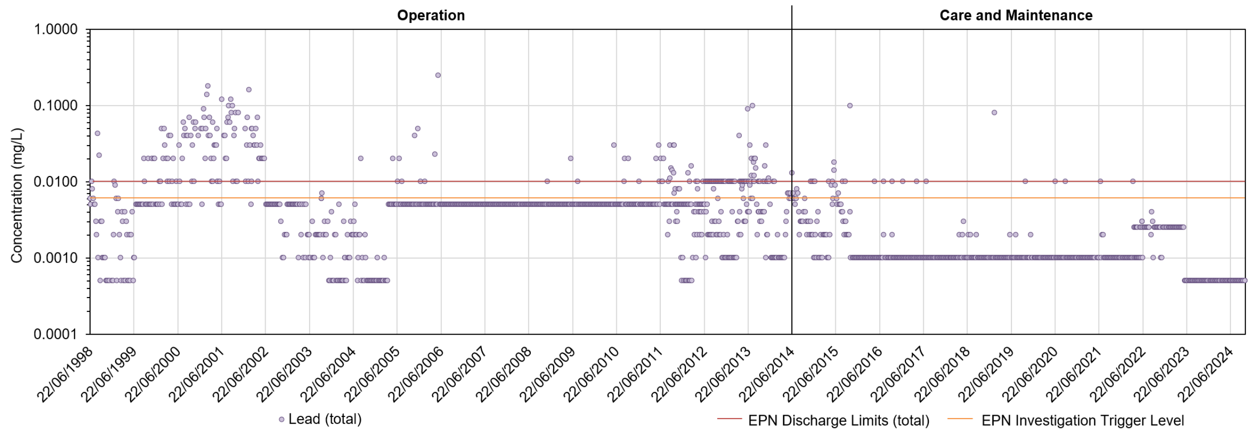


Figure 3 Lead concentrations at CMT1 (EPN = Environmental protection notice)

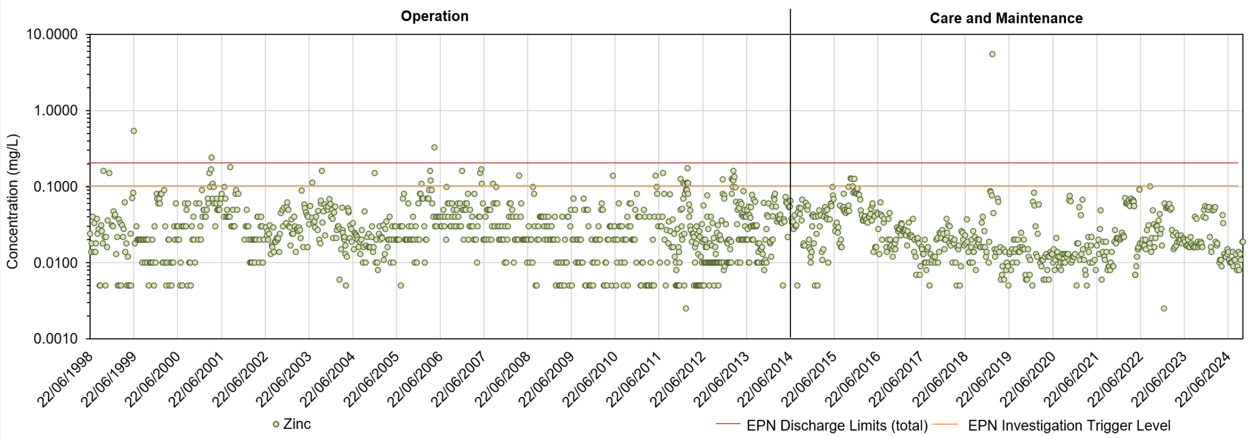


Figure 4 Zinc concentrations at CMT1 (EPN = Environmental protection notice)

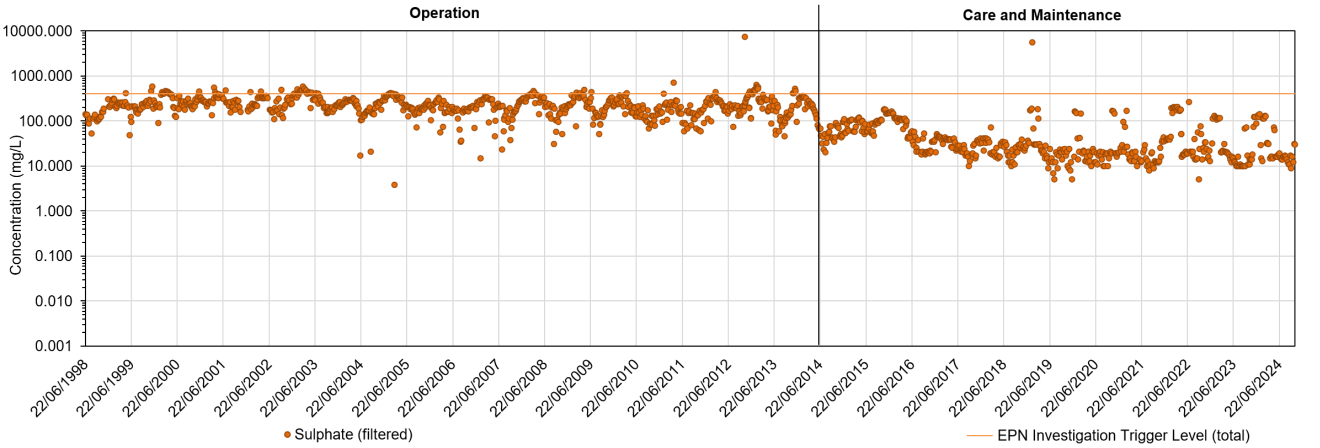


Figure 5 Sulphate concentrations at CMT1 (EPN = Environmental protection notice)

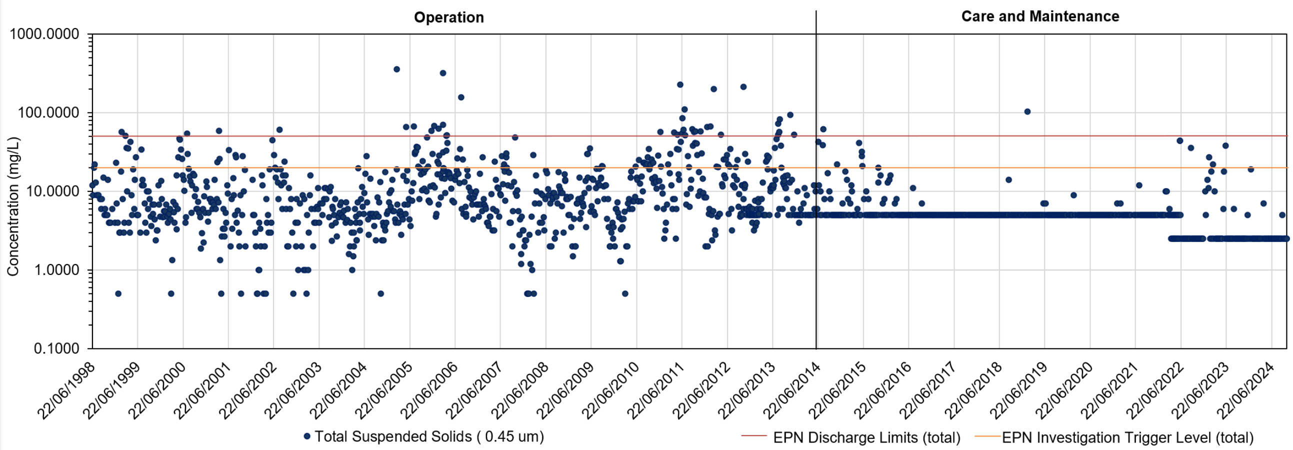


Figure 6 Total suspended solids at CMT1 (EPN = Environmental protection notice)

3.3 Implications for mine closure planning

The Mount Lyell case study demonstrates that saturated water covers can be an effective long-term control for limiting oxidation of highly reactive tailings. Importantly, improvements in downstream water quality were observed even under periods of reduced or absent neutralisation inputs, highlighting the robustness of saturation as a closure control. However, it is important to note that even small areas of beach sulphidic tailings actively form AMD which could impact downstream water quality, as observed in several studies (GHD 2013; van Balen 2019).

For closure planning, these findings highlight:

- the reduction of AMD formation from PAF tailings when tailings are inundated with water following deposition
- the importance of sufficient water cover depth to minimise oxidation of PAF tailings and limit the effects of wind fetch on tailings surfaces
- that saturation controls oxidation kinetics rather than acid-forming potential
- the requirement to maintain saturation or equivalent controls in perpetuity.

It is important to note that the TSF has been designed to safely accommodate both the decant pond and tailings deposition against the main embankment. Stability assessments indicate that the embankment achieves the required factors of safety under sunny day, flood and seismic loading conditions, demonstrating that the facility is robust under a range of operational and extreme-event scenarios.

Given the large contributing catchment area and high-rainfall setting, intermittent operation of the spillway is expected. However, the consequence category associated with spillway discharge has been assessed as low in accordance with Australian National Committee on Large Dams (ANCOLD) (2019), indicating that the associated risks are considered manageable within the current design framework.

The facility has remained in care and maintenance since 2015 and the hydrological assessments undertaken to date have not incorporated climate change projections. While this does not affect the current design assessment, it represents an area for future review. Sibanye is progressing updates to the hydrological model, including consideration of climate change impacts, as part of a future dam safety review.

The care and maintenance period at Mount Lyell provides a practical analogue for closure conditions in wet climates, although uncertainty remains regarding long-term performance under future climatic variability and without additional alkalinity input.

4 Conclusion

The Princess Creek tailings storage facility (TSF) at Mount Lyell copper mine provides a rare long-term dataset demonstrating the effectiveness of saturated water covers in limiting oxidation of reactive, sulphide-bearing tailings. Integration of geochemical, mineralogical and water quality data over a 25-year period shows that tailings saturation is associated with substantial improvements in downstream water quality and preservation of sulphide minerals.

These findings reinforce the role of saturated water covers as a viable mine closure strategy for TSFs in wet climates, particularly where tailings are highly acid forming. Long-term performance data such as those from Mount Lyell support closure planning and ongoing risk management of legacy and active tailings facilities.

Acknowledgement

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