Closure of an Australian Pit Lake With AMD Using a Terminal Water Balance as an Evaporative Sink

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Abstract

Pit lakes often present environmental risks due to poor water quality. However, hydraulic terminal sink water balances can prevent transport of contaminated pit lake waters to receiving environments.

Closure of the T5 pit void in Western Australia was expected to result in Acid and Metalliferous Drainage (AMD). However, predictive modelling indicated that, if not backfilled above long-term equilibrium water levels at closure, the pit lake would function as a hydraulic terminal sink.

Monitoring over four years validated a terminal pit lake water balance such that AMD was evapoconcentrated and stored within the pit lake, preventing transport of AMD to the receiving environment.

Keywords: Pit lake, AMD, Terminal sink, Australia, Mine closure

Introduction

Pit lake water quality risk

Pit lakes often present environmental risks due to poor water quality. However, in an arid climate, pit lake evaporation rates can exceed influx rates, causing the lake to function as a hydraulic terminal sink, with water levels in the pit remaining below surrounding groundwater levels (Castendyk, 2011). A negative pit lake water balance may prevent transport of contaminated pit lake waters to sensitive receiving environments as either through-flow or flow-through pathways.

Study site

Tallering Peak iron ore mine is located in the semi-arid Midwest mining region of Western Australia, approximately 175 km east of Geraldton and 300 km north of Perth. The mine consisted of mined pits and associated waste rock dumps (T3, T4, T5 and T6). The Tallering Peak Operation commenced production in 2004 and was concluded in mid-2014 after ten years of continuous production

The Mt Gibson Tallering Peak project regional geology is characterised by Archaean meta-sediments and volcanics with hematite/magnetite-quartz Banded Iron Formations (BIFs), chloritic sedimentary/volcanic horizons and some dolerite intrusions (1:250,000 Yalgoo Sheet Geology Series Map). The geology of the T5 pit is granite bedrock with hematite/magnetite BIF intrusions and some dolerite dykes overlain by surface alluvium. The BIF sequence is striking north-west/south-east, steeply dipping with dolerite dykes crossing perpendicular to the BIF intrusions. Tertiary alluvial colluviums surround the site and have also been deposited along drainage channels to the south of the Tallering Peak project. Some geologies are strongly potentially acid forming (PAF).

Regional groundwater in the study area occurs within a semi-confined fractured aquifer system with unconfined porous medium aquifers in weathered zones and alluvium. Groundwater flow follows topography towards the Greenough River to the south-west of the site. Pre-mining groundwater levels adjacent to the T5 pit in 2001 indicated average groundwater levels of 239 m AHD. Groundwater levels are predominately recharged by rainfall recharge of 1–2 mm per year and is brackish at 2,000–4,000 mg/L total dissolved solids (TDS).

Closure strategy

The T5 pit lake closure strategy is discussed in detail as a case study in McCullough *et al.* (2013).

Disposal of mining waste at the bottom of pit lakes is often a preferred management strategy (Puhalovich & Coghill, 2011; Schultze *et al.*, 2011). However, regulatory requirements for a fully backfilled pit void was predicted to form a through-flow system which would therefore be likely to introduce AMD into regional groundwater and toward a seasonal creek line in the south-west. Furthermore, there was a 5% chance after 35 years that the fully backfilled pit water level would discharge to these surface waters of the Greenough River catchment.

Water balance modelling indicated the T5 pit lake would function as hydraulic terminal sink if not backfilled above long-term equilibrium water levels at dewatering cessation in 2013. This terminal sink closure strategy was preferable to a complete backfill strategy that would result in AMD transport to regional surface and groundwater receiving environments.

The partially backfilled option for the T5 pit was based on a known volume of backfilled PAF material. After closure, the void was expected to fill mostly through groundwater inflows and reach an equilibrium level around five years thereafter. Equilibrium final pit lake water levels would be above backfill, with PAF oxidation rates reduced by this subaqueous placement (Gammons, 2009). A final evaporative sink was predicted to also entrain AMD contaminated waters away from sensitive environmental receptors such as a nearby ephemeral creek which flows into the Greenough River.

Nevertheless, pit lake groundwater interactions are not well understood (Schultze *et al.*, 2022) especially so in fractured rock geologies, and water balance modelling can be difficult under these conditions (Castendyk *et al.*, 2015). Assumptions of evaporation rates as a pit lake fills can also be over-estimated (McJannet *et al.*, 2017). This paper reports on surface and groundwater level and quality monitoring to examine the performance of this closure strategy for the T5 pit lake.

Methods

Water quality sampling

Water quality sampling was in accordance with McCullough *et al.* (2010); Gammons and Tucci (2011).

T5 water column profiles were made twice-yearly from 2013–2016 with a multiparameter water quality meter for temperature, pH, dissolved oxygen (as % saturation) and specific conductance (SC) and water level height was recorded. Water samples were also collected from surface and bottom pit lake waters with a van Dorn sampler. Groundwater samples were taken from an established piezometer network around the T5 pit lake (fig. 1), especially downgradient, and depth to groundwater was recorded.

Water samples were analysed for a suite of inorganic solutes including metal(loid)s on an Inductively Coupled Plasma-Mass Spectrometer/Atomic Emission Spectrometer (ICP-MS/AES).

Data analysis

Time-depth profile contour plots were created for physico-chemical pit lake water quality parameters collected during the monitoring period. Piper plots were prepared from solute concentration data to define water sample sites. Groupings of sampling points were undertaken based on major ion chemistry and geographical location. A contour plot was prepared to demonstrate surface and groundwater level relationships in 2016.

Results

Contour plots for pit lake temperature suggest thermal vertical stratification occurring as expected over summer and autumn months (fig. 2). This stratification is typical of Western Australian pit lakes which usually stratify once seasonally as a monomictic lake (Kumar *et al.*, 2013). Dissolved oxygen was restricted to surface waters during this time due to this mixing inhibition. pH of the T5 pit became more acidic over time.

Alkaline backfilled geologies and groundwater appeared to initially buffer acidity produced through oxidation of PAF material in pit wall geologies and as waste backfill.

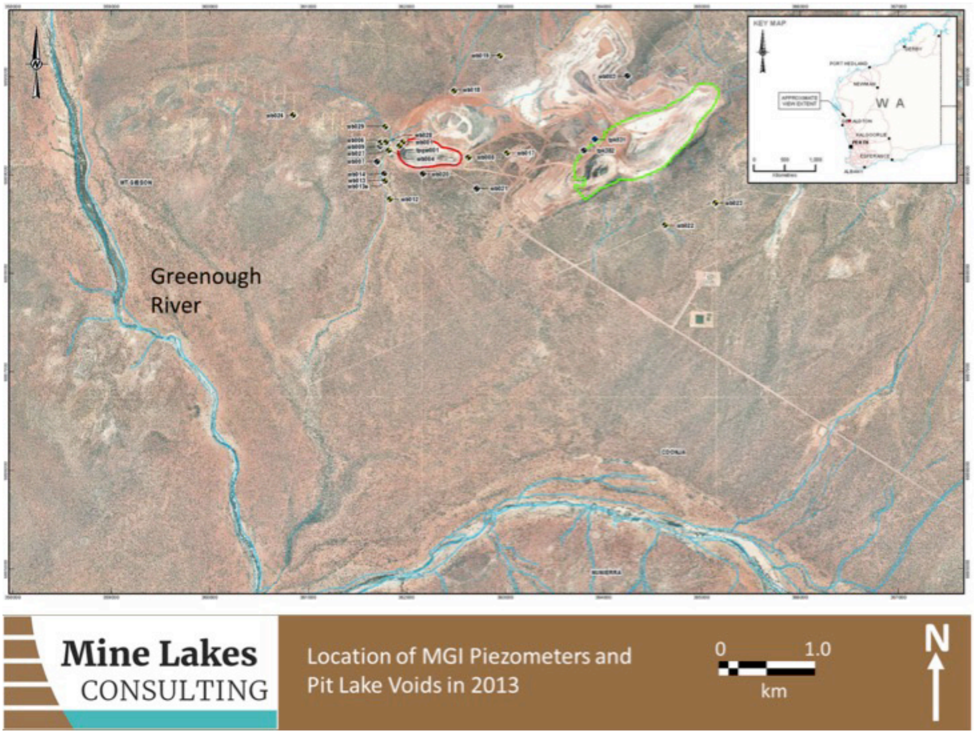

***Figure 1** Location of MGI piezometers and pit lake voids in 2013.*

However, a minimum pH of 3.6 was recorded near the end of the monitoring period.

Two distinct water types were defined by major ion concentrations (fig. 3). Type 1 water included samples collected from the T5 pit, T6 pit and sampling point TPK531. Type 2 water included all remaining sampling points surrounding the T5 pit. Generally, Type 1 water demonstrated lower pH and alkalinity, and elevated EC, Ca, Mg, SO4, Al, Co, Cu, Mn, Ni and Se concentrations with respect to Type 2 water samples.

Following three years of filling, the pit lake was around 20 m depth and 3.5 ha area. A strong groundwater gradient existed toward the T5 pit lake (fig. 4). A similar gradient presented to the T6 pit void to the east.

Conclusions

Pit lake water balance modelling indicated that the T5 pit lake would function as an evaporative hydraulic terminal sink if not backfilled above long-term equilibrium water levels at closure. This terminal sink closure strategy for a pit lake with water degraded by AMD was preferred by regulators and other key stakeholders to the previously required complete backfill strategy that was expected to result in AMD transport to regional surface and groundwater receiving environments with subsequent degradation of their socio-environmental values. A case for relinquishment of mining tenements associated with the T5 pit lake was submitted to regulators in mid-2019. After reviewing the case, regulators confirmed that the groundwater and pit lake data presented to validate the terminal pit lake closure strategy was adequate and no further monitoring was necessary.

Although a terminal pit lake water balance may be a preferred closure strategy for some pit lakes, decision-making assessments (including comprehensive risk assessments e.g. (McCullough & Sturgess, 2020)) should form part of all pit lake water balance strategies (Vandenberg *et al.*, 2022).

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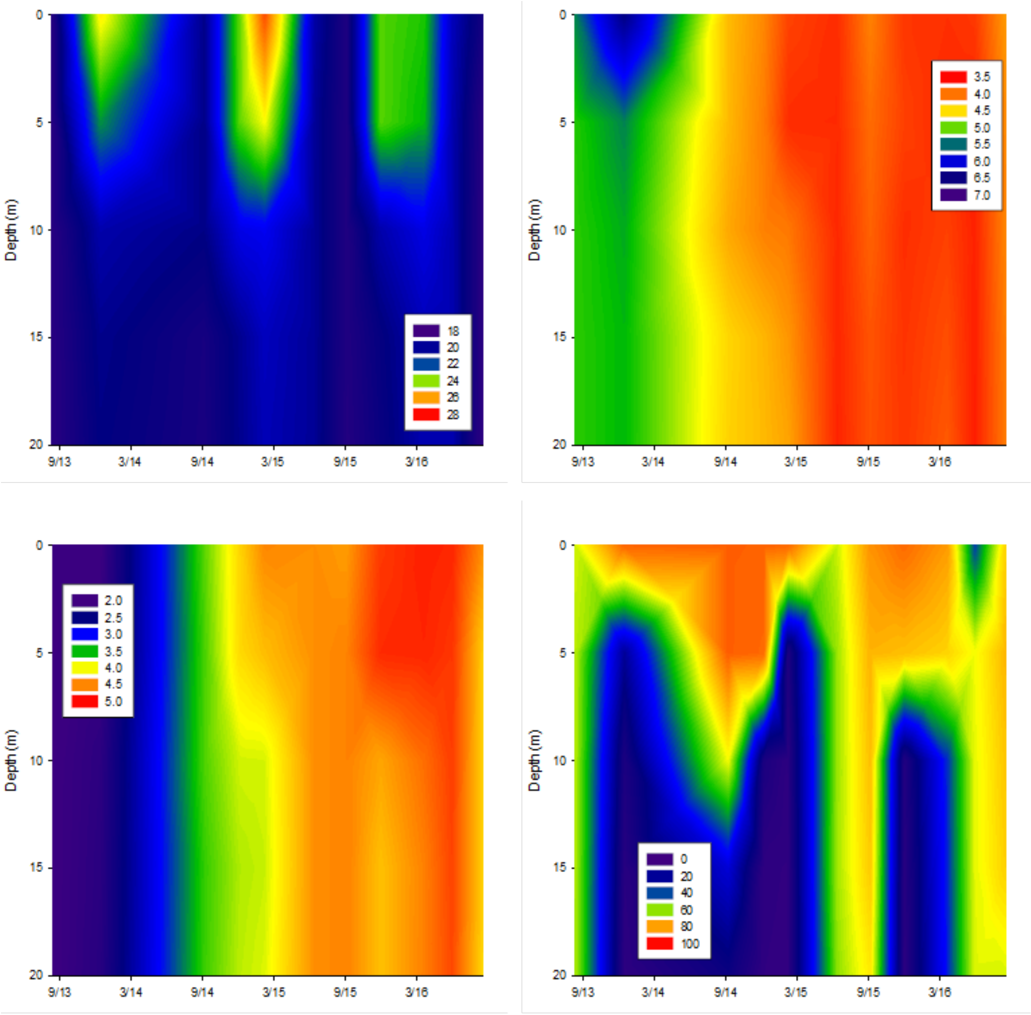

Figure 2 *Depth/time contour profiles for mean T5 hydrochemistry 2013–2016. Clockwise from top left: temperature (°C), pH, dissolved oxygen (% saturation) and specific conductance (mS/cm).*

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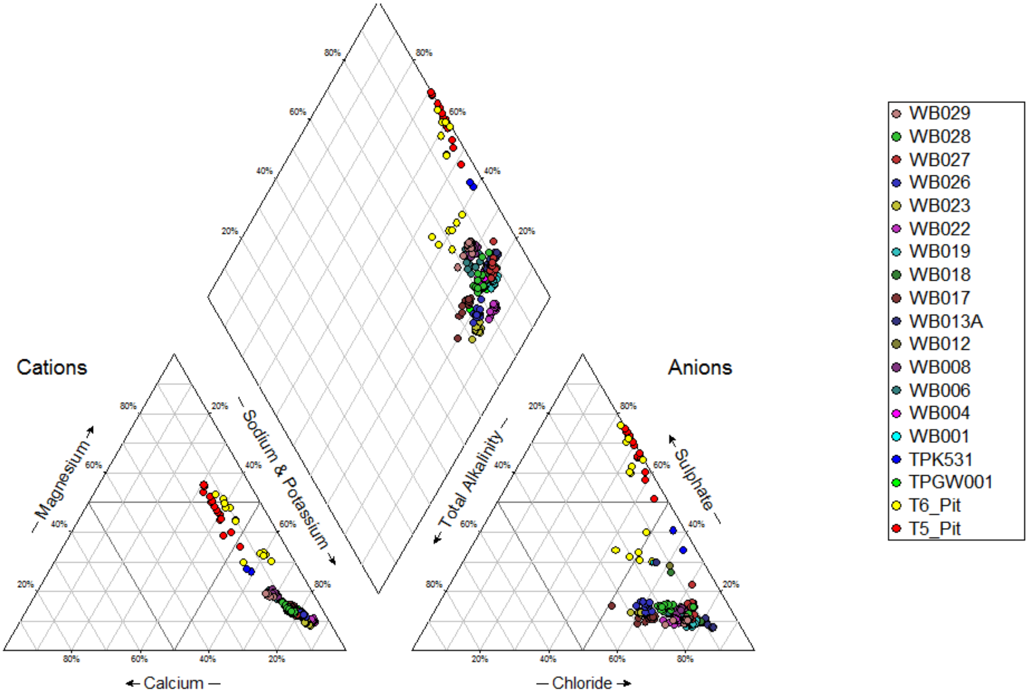

Figure 3 *Piper plot of 2015 groundwater and pit lake water quality samples.*

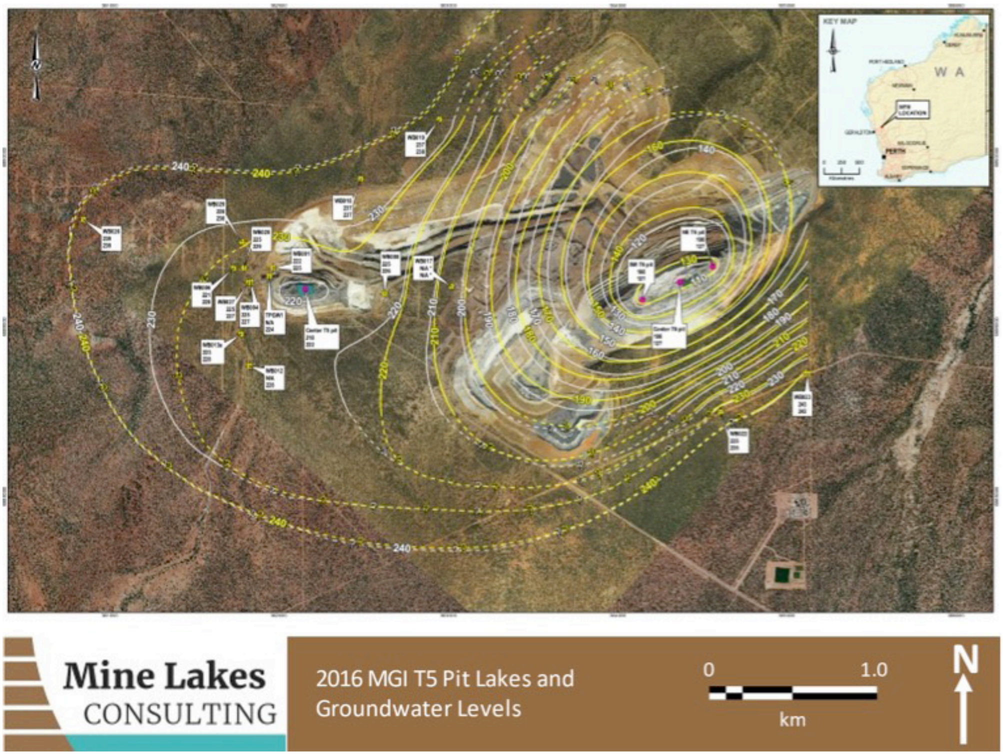

Figure 4 *2016 MGI T5 Pit Lakes and Groundwater Levels*

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