Abstract

Mine pit lakes typically present significant mine closure liabilities in perpetuity though large volumes of contaminated waters. Lake Kepwari represents a significant achievement in mine closure planning as the first successfully rehabilitated and relinquished pit lake in Western Australia.

Lake Kepwari uses seasonal flow to remediate water quality and provide ecological connectivity to the broader catchment. State government endorsed the approach with a formal opening in December 2020 with significant infrastructure developments. Lake Kepwari demonstrates pit lake planning that presents a significant local opportunity for the mining town with regional benefits to state tourism and recreational opportunities too.

Keywords: Pit Lake, Flow-through, End Uses, Australia, Mine Closure

Introduction

The Collie Coal Basin is the centre of the coal mining industry in Western Australia and is located approximately 160 km south-south-east of Perth. Waterways in southwestern Western Australia, including the Collie River, play an important role in the lives of First Nations Noongar people; their connection to the Collie River is reflected in their spiritual beliefs and its role as a source of food, water and recreation.

Mining began in the Lake Kepwari (WO5B) pit with diversion of the Collie River South Branch (CRSB) around the western void margin (Figure 1). Rehabilitation works on Lake Kepwari initially started in the 1980s in parallel with open-cut mining operations. When mining ceased in 1997, most reactive overburden dumps and exposed coal seams were covered with waste rock to cover PAF sources. At completion of the mining activities, the WO5B mine void edges were backfilled and graded to 10° to 5 m below water level to form beaches and an island with more than 2 Mm³ of soil moved. The catchment was then revegetated by direct seeding with more than 60 species of native vegetation. The diversion channel was then revegetated by direct seeding with more than 60 species of native vegetation. The diversion channel was then revegetated by direct seeding with more than 60 species of native vegetation. 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Closure strategy trial

Heavy rainfall in August 2011 led to the CRSB overtopping the embankment separating it from Lake Kepwari. Approximately 30 m of ground failed and 2 GL of CRSB water flowed through Lake Kepwari, discharging through culverts in the NE and NW sides of the Lake (McCullough et al., 2013). This flow substantially improved lake water quality and ecosystem values (McCullough et al., 2012), indicating that maintaining the lake as a seasonal flow through system would provide a leading practice closure strategy for the lake. The flow-through event did not significantly impact upstream downstream CRSB values (McCullough et al., 2013).

A literature review, coupled with engagement, provided confidence to stakeholders that the approach was good international practice. Following this engagement, including community presentations, a flow-through trial was initiated to assess the benefits of this leading practice management option. The trial was run between 2012 and 2014 with over two years of diverted main-flow and one year of no flow (due to low rainfall). Regular quarterly assessment of biota and chemistry of both Lake Kepwari and the CRSB, and annual reporting of the findings to regulators and community were key components of the trial (McCullough & Harkin, 2015).

Premier Coal obtained approval to permanently divert the Collie River back to its original path through the mine void in November 2018. Recent rehabilitation activities to facilitate ongoing flow through included: widening the Collie River inlet and outlets to allow total flow-through the lake; rehabilitating the breach; and backfilling the diversion channel adjacent to the Lake surrender area. Premier Coal engaged local businesses that employed local people to do this work and civil works enabling the

<table>
<thead>
<tr>
<th>Site</th>
<th>pH @ 25°C</th>
<th>EC (μS/cm)</th>
<th>Oxygen</th>
<th>Suspended Solids</th>
<th>Al</th>
<th>As</th>
<th>Fe</th>
<th>Mn</th>
<th>Ni</th>
<th>Zn</th>
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<tbody>
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<td>6.7</td>
<td>4,970</td>
<td>9.1</td>
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<td>0.01</td>
<td>0.001</td>
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<td>0.060</td>
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</tr>
<tr>
<td>Outlet</td>
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<td>2,390</td>
<td>8.1</td>
<td>1.0</td>
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<td>0.001</td>
<td>0.13</td>
<td>0.0</td>
<td>0.007</td>
<td>0.04</td>
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</table>

Figure 1 Location of Lake Kepwari in Western Australia (left) and conceptual model of Lake Kepwari flowthrough design (right) showing historical CRSB channel in black, previous river diversion in dark grey and flow through lake in light grey (DIIS, 2016).

Table 1 Inlet and outlet water quality on 8/11/2018. All values filtered as mg/L unless otherwise stated.
Table 2 Lake Kepwari discharge water quality on 17 October 2018 (dissolved as μg/L).

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>Cd</th>
<th>Cr</th>
<th>Cu</th>
<th>Mn</th>
<th>Ni</th>
<th>Pb</th>
<th>Se</th>
<th>Zn</th>
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<tbody>
<tr>
<td>Kepwari</td>
<td>0.05</td>
<td>0.00002</td>
<td>0.00043</td>
<td>0.012</td>
<td>0.026</td>
<td>0.007</td>
<td>0.00068</td>
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<tr>
<td>Void</td>
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<td>**0.005</td>
<td>&lt;0.002</td>
<td>**0.11</td>
<td>0.1</td>
<td>**0.548</td>
<td>–</td>
<td>–</td>
<td>3.37</td>
</tr>
</tbody>
</table>


Figure 2 Time-series graph of Lake Kepwari pH and EC historically, during and after flow-through began (after McCullough et al., 2010; McCullough et al., 2012; McCullough, 2015). Dotted teal regression line indicates pit lake pH and EC trends over time. Dashed brown line indicates date of breach.
flow-through were completed in June 2019. Yancoal surrendered the Lake Kepwari area from its mining tenement in August 2020.

**Closure monitoring**

Monitoring results showed downstream river water quality and availability was not significantly degraded by flow-through when discharge occurred during high CRSB flow with concomitant high lake water dilution in the downstream CRSB reaches (McCullough & Schultze, 2015). Furthermore, relative to upstream, downstream river water quality may be improved through trapping suspended solids including particulate forms of nutrients to the lake benthos and removal of soluble forms of phosphorus by co-precipitation with dissolved aluminium and iron from internally-generated lake AMD (McCullough & Schultze, 2018).

Recent monitoring of Lake Kepwari and a similarly large and age pit lake from the lease indicates that a trend of water quality improvement has occurred since implementation of innovative flowthrough. Lake pH is higher than historic and even previously reported levels, and importantly, on an upward trend from acidic to circum-neutral levels (Figure 2, top). Similarly, EC continues to decline from brackish to fresh salinities (Figure 2, bottom). Lake Kepwari discharge water quality also meets default national guideline values for typical mining related contaminants of potential concern (COPC) (ANZG, 2018) for aquatic protection (Table 2).

**Regional benefits**

Kepwari is a word in the indigenous Wilman language meaning “playing in water”, and a range of water sports may be enjoyed at Lake Kepwari. Closure aims of the lake have provided a potential recreation resource for water skiing, diving and other aquatic recreational pursuits.

Collie is a town that has traditionally been reliant on mining and power generation to employ community members and support local businesses. Tourism is also becoming an important driver of a more diversified economy for Collie. The enhancement of nature-based tourism has potential to contribute to economic growth and diversification, supporting a more sustainable post-mining regional community. Transformation of Lake Kepwari into a recreation hub for water sports is expected to attract many tourists and visitors, which will provide a boost for businesses around Collie. Early estimates anticipate that after three years, Lake Kepwari is expected to attract overnight stays and day trip visitors, contributing significantly to the local economy.

State Government identified Lake Kepwari as a key development project in the South West region and committed $5.7

*Figure 3 Water-based recreation is a planned end use of Lake Kepwari.*
million to realising this vision. Recent works commissioned by government to develop the Lake into a recreation hub included a swim beach, picnic areas, campground, toilets, dual lane boat ramp and jetty, parking bays for 85 boat trailers and 65 cars. Upgrades to the entrance road, a new bridge over the Collie River and signage throughout the area has turned the area into a watersports landmark.

Conclusions
Over 100 years of coal mining in Collie resulted in many pit lakes as a lake district (sensu McCullough & Van Etten, 2011). Pit lakes in Collie to date, and also with current closure planning, are isolated from regional surface waters using closure approaches largely unchanged since open cut mining began (Lund et al., 2012). With the exception of Lake Kepwari, all are acidic due to AMD production from oxidation of regional low sulfide lithologies (McCullough et al., 2010). The Lake Kepwari catchment-based flow-through closure strategy challenges these practices by using natural catchment attenuation and dilution processes to remediate water quality over a long-term as a passive treatment (McCullough & Schultze, 2018). AMD produced in the backfilled waste rock and pit shell is neutralised by net alkaline river water by regular seasonal flowthrough. Further alkalinity is generated by biological processes (Lund & McCullough, 2009) and mineral acidity is precipitated to lake sediments (Neil et al., 2009) e.g., through absorption onto dissolved organic matter (DOM). The net result yields a seasonal thermally stratified freshwater lake of circum-neutral pH (Kumar et al., 2013). Lake Kepwari is now part of the Collie River Waugal Aboriginal Heritage Site, which includes the Collie River system. Lake Kepwari will be an important landmark for the mining industry as a good example of how rehabilitating a mine site requires addressing more than just terrestrial landforms.

Acknowledgements
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References


