Rehabilitaion of Lake Kepwari: a Previously Acidic Mine Lake in Western Australia

Cherie D. McCullough

Mine Lakes Consulting, PO Box 744, Joondalup DC, WA 6005, Australia, cmccullough@minelakes.com

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 thefirst 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^{o} to 5 m below water level to form beaches and an island with more than 2 Mm^3 of soil moved. The catchment was then revegetated by direct seeding with more than 60 species of native vegetation. The diversion channel was maintained to permanently divert the CRSB around the pit void to meet requirements of the 1997 Western Australian State agreement mine closure plan for Lake Kepwari as a "closed catchment lake".

To accelerate filling of the pit, additional water was provided through saline first flushes from the seasonal CRSB under a surface water license (Salmon *et al.*, 2017). CRSB water quality is typically brackish and highly tannin stained, with moderate eutrophication. The lake was rapid-filled by these winter diversions between 2002–2008 through a valve-regulated offtake when river flow was sufficiently high. The lake reached its capacity volume, as limited by overflow culverts, in 2004. The final volume of Lake Kepwari is around 32×10^6 m^3, with a maximum depth of around 65 m, perimeter of 5.4 km and surface area of 1.0 km^2 (Lund *et al.*, 2012).

Although the input of CRSB water initially raised the pH to above pH 7, the pH then fell below 4 once river inflows ceased. This low pH and associated elevated concentrations of some metals and metalloids reduced water quality values and restricted end use opportunities. However, the lake remained visually spectacular with extremely high transparency due to an absence of phytoplankton, restricted by low phosphorus due to AMD (Kumar *et al.*, 2016).

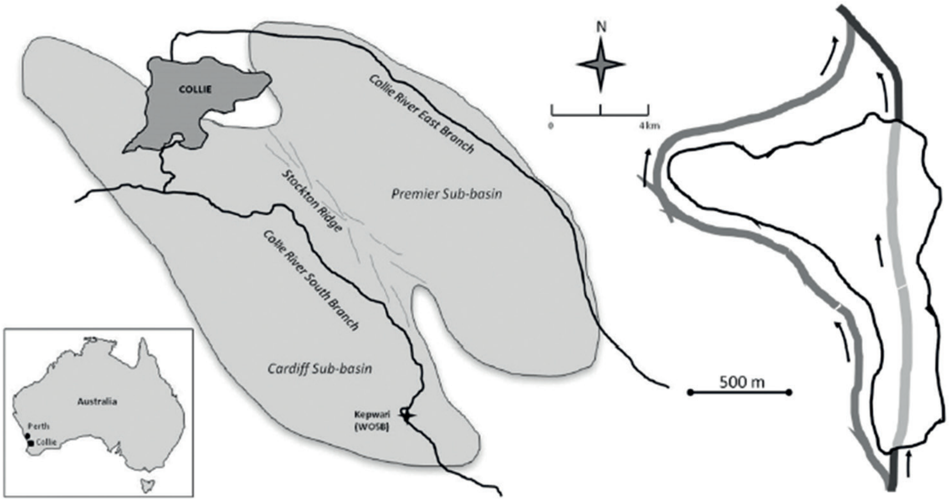

Figure 1 *Location of Lake Kepwari in Western Australia (left) and conceptual model of Lake Kepwari flowthrough design (right) showing historical CRSB channel in black, previous river diversion in dark grey and flow through lake in light grey (DIIS, 2016).*

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 1 *Inlet and outlet water quality on 8/11/2018. All values filtered as mg/L unless otherwise stated.*

Site	pH @ 25C	EC (µS/cm)	Oxygen	Suspended Solids	Al	As	Fe	Mn	Ni	Zn
Inlet	6.7	4,970	9.1	13.0	0.01	0.001	0.36	2.2	0.060	0.03
Outlet	7.6	2,390	8.1	1.0	0.04	0.001	0.13	0.0	0.007	0.04

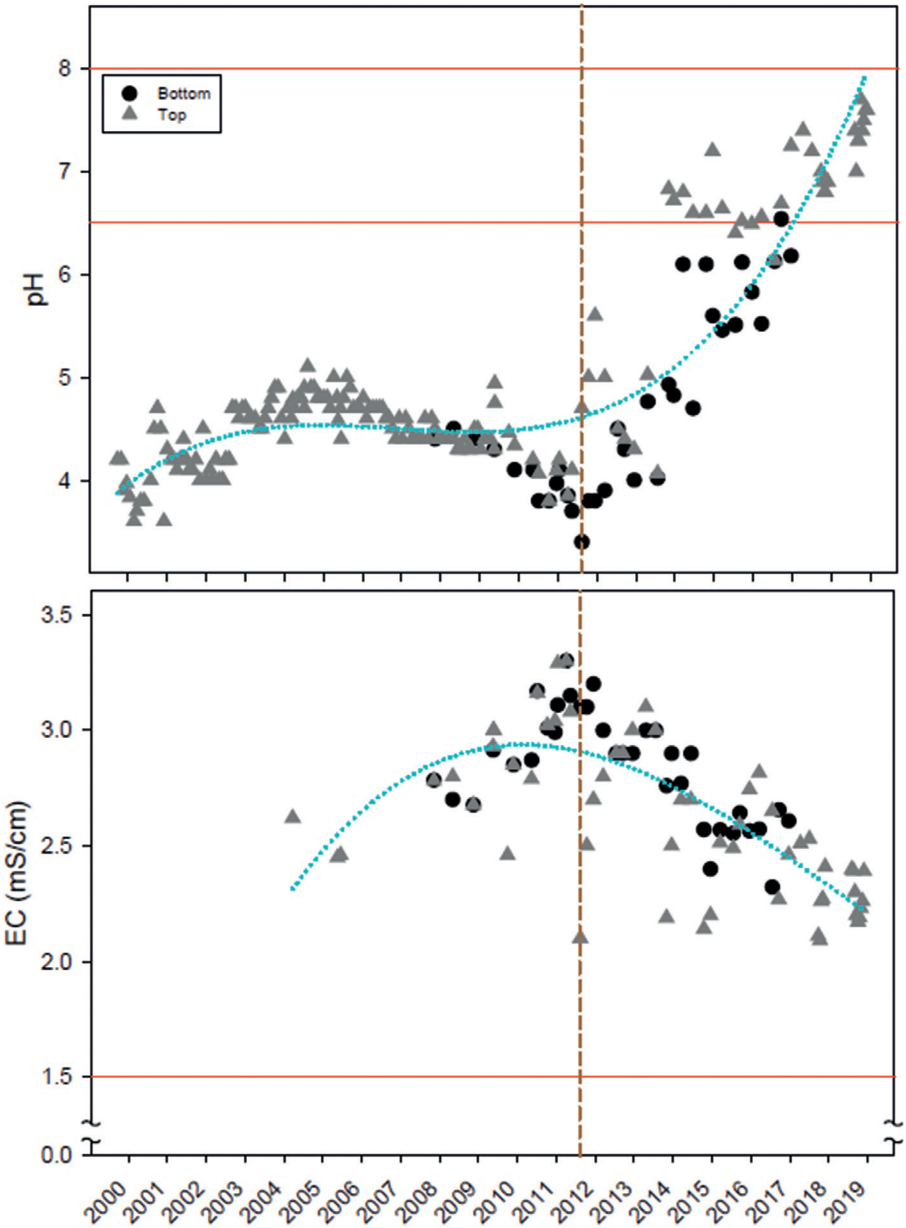

Figure 2 *Time-series graph of Lake Kepwari pH and EC historically, during and after flow-through began (after McCullough et al., 2010; McCullough et al., 2012; McCullough, 2015). Dotted teal regression line indicates pit lake pH and EC trends over time. Dashed brown line indicates date of breach.*

Table 2 *Lake Kepwari discharge water quality on 17 October 2018 (dissolved as µg/L).*

	Al	Cd	Cr	Cu	Mn	Ni	Pb	Se	Zn
Kepwari	0.05	0.00002	0.00043	0.012	0.026	0.007	0.00068	0.00015	0.053
Void	**83**	**0.005**	<0.002	**0.11**	0.1	**0.548**	–	–	3.37

Bold font indicates ANZG (2018) guidelines meet for freshwater aquatic ecosystem protection., – = No data, *As total.

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

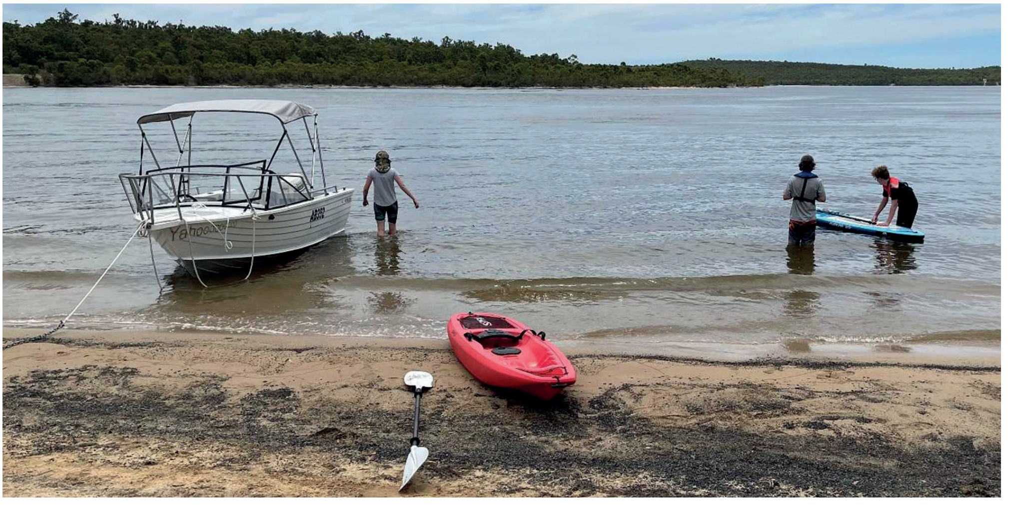

Figure 3 *Water-based recreation is a planned end use of Lake Kepwari.*

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

Many thanks to the previous and current Premier Coal and DWIR staff and CDM's consulting and research colleagues and students for collecting monitoring data.

References

ANZG (2018). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian state and territory governments (ANZG), Canberra ACT, Australia. Available at www.waterquality.gov.au/anz-guidelines.

***Figure 4** The lake is expected to attract visitors to the region.*

DIIS (2016). Leading Practice Sustainable Development Program for the Mining Industry - Preventing Acid and Metalliferous Drainage Handbook. Department of Industry, Innovation and Science (DIIS), Canberra, Australia. 221p.

Kumar, N. R.; McCullough, C. D. & Lund, M. A. (2013). Pit lakes in Australia. In, Acidic pit lakes – the legacy of coal and metal surface mines, Geller, W.; Schultze, M.; Kleinmann, R. & Wolkersdorfer, C. Springer, Heidelberg, Germany, 342-361pp.

Kumar, R. N.; McCullough, C. D.; Lund, M. A. & Larranãga, S. (2016). Assessment of factors limiting algal growth in acidic pit lakes—a case study from Western Australia, Australia. Environmental Science and Pollution Research. 23: 5915–5924.

Lund, M. A. & McCullough, C. D. (2009). Biological remediation of low sulphate acidic pit lake waters with limestone pH neutralisation and amended nutrients Proceedings of the International Mine Water Conference. Pretoria, South Africa. International Mine Water Association, 519-525pp.

Lund, M. A.; McCullough, C. D. & Kumar, N. R. (2012). The Collie Pit Lake District, Western Australia: an overview. Proceedings of the International Mine Water Association (IMWA) Congress. Bunbury, Australia. International Mine Water Association (IMWA), 287-294pp.

McCullough, C. D. (2015). Consequences and opportunities of river breach and decant from an acidic mine pit lake. Ecological Engineering. 85: 328-338.

McCullough, C. D.; Ballot, E. & Short, D. (2013). Breach and decant of an acid mine lake by a eutrophic river: river water quality and limitations of use. Proceedings of the Mine Water Solutions 2013 Congress. Lima, Peru. Infomine Inc., 317-327pp.

McCullough, C. D. & Harkin, C. (2015). Engineered flow-through closure of an acid pit lake; a case study. Proceedings of the International Mine Closure 2015 Congress. Vancouver, Canada. Infomine, 1-10pp.

McCullough, C. D.; Kumar, N. R.; Lund, M. A.; Newport, M.; Ballot, E. & Short, D. (2012). Riverine breach and subsequent decant of an acidic pit lake: evaluating the effects of riverine flow-through on lake stratification and chemistry. Proceedings of the International Mine Water Association (IMWA) Congress. Bunbury, Australia. 533-540pp.

McCullough, C. D.; Lund, M. A. & Zhao, L. Y. L. (2010). Mine Voids Management Strategy (I): Pit lake resources of the Collie Basin. Department of Water Project Report MiWER/ Centre for Ecosystem Management Report 2009-14, Edith Cowan University, Perth, Australia. Unpublished report to Department of Water, Government of Western Australia. 250p.

McCullough, C. D. & Schultze, M. (2015). Riverine flow-through of mine pit lakes: improving both mine pit lake and river water quality values? Proceedings of the joint International Conference on Acid Rock Drainage ICARD/ International Mine Water Association (IMWA) Congress. Santiago, Chile. 1903- 1912pp.

McCullough, C. D. & Schultze, M. (2018). Engineered river flow-through to improve mine pit lake and river water values. Science of the Total Environment. 640-641: 217-231.

McCullough, C. D. & Van Etten, E. J. B. (2011). Ecological restoration of novel lake districts: new approaches for new landscapes. Mine Water and the Environment. 30: 312-319.

Neil, L. L.; McCullough, C. D.; Lund, M. A.; Tsvetnenko, Y. & Evans, L. (2009). Toxicity of acid mine pit lake water remediated with limestone and phosphorus. Ecotoxicology and Environmental Safety. 72: 2,046-2,057.

Salmon, S. U.; Hipsey, M. R.; Wake, G. W.; Ivey, G. N. & Oldham, C. E. (2017). Quantifying lake water quality evolution: coupled geochemistry, hydrodynamics, and