Riverine breach and subsequent decant of an acidic pit lake: evaluating the effects of riverine flow-through on lake stratification and chemistry

Clint D. McCullough[1,2], R. Naresh Kumar[2], Mark A. Lund[2], Michelle Newport[2], Elmien Ballot[3], Digby Short[3]

[1]*Golder Associates Pty Ltd, West Perth, Western Australia 6005, Australia*
[2]*Mine Water and Environment Research Centre (MiWER), Edith Cowan University, 270 Joondalup Drive, Joondalup, Western Australia 6027, Australia*
[3]*Premier Coal, Collie, Western Australia 6225, Australia*

Abstract

Breach and subsequent decant of an acidic brackish pit lake in the Collie Coal region in south-western Australia occurred during flooding of a pre-mining diverted eutrophic river. Inflowing fresher river water with high alkalinity and nutrient concentrations settled over more saline and acidic pit lake water. This created a halocline with better mixoliminion water quality and monimolimnion water quality typical of the pre-breach lake. Flow-through may represent the best long-term mine closure option for this and other pit lakes in the state and internationally where pit lake water quality degrades over time when excised from regional water systems.

Keywords: breach, river, flow-through, fishery, pit lake, AMD

Introduction

Designing pit lakes as flow-through systems by connecting them to rivers is receiving more attention as a key element for mine closure. Flow-through systems cannot only maintain pit lake water quality but may also minimise social and environmental risks. Depending on the water quality that can be attained in the pit lake this may enhance the scope for beneficial end uses such as recreation and wildlife habitat.

Due to operational and regulatory practicalities for many open-cut mines, pit lakes are common legacies for many mine closures. Pit lakes may form in open cut mine voids that extend below the water table when they subsequently fill with ground and surface waters upon cessation of mining and associated dewatering operations. Pit lake water quality is often degraded by acid and metalliferous drainage (AMD) leading to acidic water with elevated metal concentrations (McCullough and Lund 2006). This may leave liability risks at mine closure and may also reduce the end use values and opportunities. Closure guidelines also increasingly require consideration of post-mining land uses of equivalent capacity to pre-mining conditions (Jones and McCullough 2011). Good pit lake closure minimises long term pit lake liabilities and maximises benefits to stakeholders and the environment, but is often neglected in mine closure planning (McCullough et al. 2009; McCullough and Van Etten 2011).

One strategy that is increasingly used to maintain pit lake water quality from both salinisation and acidification is to direct river water (often back to its original course) through pit lakes (Schultze et al. 2011). This strategy can maintain pit lake water quality so that beneficial end uses such as irrigation, recreation and wildlife habitat can be achieved.

The south west of Western Australia is regarded as having a highly biodiverse aquatic flora and fauna. The mining town of Collie is located here and is the centre of the coal mining industry in Western Australia (Figure) (Lund and McCullough 2008). Land uses in the Collie Coal basin are predominantly coal mining, timber production, power generation and agriculture, however in the broader Collie River catchment, approximately 79% is state forest. The recreation and nature conservation values of the forest areas are highly regarded along with the recreational opportunities provided by nearby reservoirs and other surface waters, including some pit lakes. These values have led to increased promotion of the area for wildlife and recreation-based tourism by local business associations and local government.

Underground and open cut coal mining has taken place in the Mediterranean climate of the Collie Coal basin since 1898 and has resulted in the formation of at least 13 pit lakes that range from <1–10 ha in surface area, <10–70 m in depth, 1–50 years in age and in pH from 2.4–5.5 (McCullough et al. 2010). These lakes differ in the extent of rehabilitation and water quality, although all are acidic due to AMD.

Mining of the Lake Kepwari void (WO5B) began with diversion of the seasonal Collie River South Branch (CRSB) away from the pit site and around the western margin and ceased in 1997. During rehabilitation, reactive overburden dumps and exposed coal seams were covered with waste rock, battered and revegetated with endemic flora. To further reduce wall exposure and acid production, the lake was rapid-filled by a diversion from the CRSB over three winters until 2005 (McCullough et al. 2010). Although the river water initially raised water pH to above pH 5, subsequently it had declined below pH 4 by 2011 and displayed elevated metals and metalloids concentrations as a result of acidity inputs, most likely though in-catchment acidity generation and acidic groundwater inflow (Müller et al. 2011).

The volume of the lake is around 32×10^6 m^3, with a maximum depth of 65 m and surface area of 103 ha. Lake Kepwari is proposed as a recreation resource for primary water contact activities such as swimming and water skiing. Low pH and high metal concentrations currently restrict use of the lake for these purposes (Neil et al. 2009).

During the third week of August 2011, a rainfall of 85.6 mm (BOM 25/03/2012) in Collie over 48 h led to high flows in the CRSB. The water level in the River rose, overtopping and then eroding the engineered northern dyke wall that separated it from the lake. As a result, water levels in Lake Kepwari rose 1.7 m over the Lake's new surface area of 106 ha representing around 6% of the lake volume. Lake water then decanted through a previously designed outlet before overtopping this and then decanting back through the breach as River levels dropped. There is now a permanent connection to the river and lake at the breach point and through the previously designed lake overflow.

The river breach event in Lake Kepwari has provided an opportunity to evaluate and understand the potential benefits of flow-through system as a pit lake closure strategy. There are not many such examples in Australia for pit lakes and also in other parts of the world with similar climatic conditions. This study compared the data collected from a previous studies conducted prior to the breach with the monitoring data collected immediately post breach to track the changes in pit lake water quality.

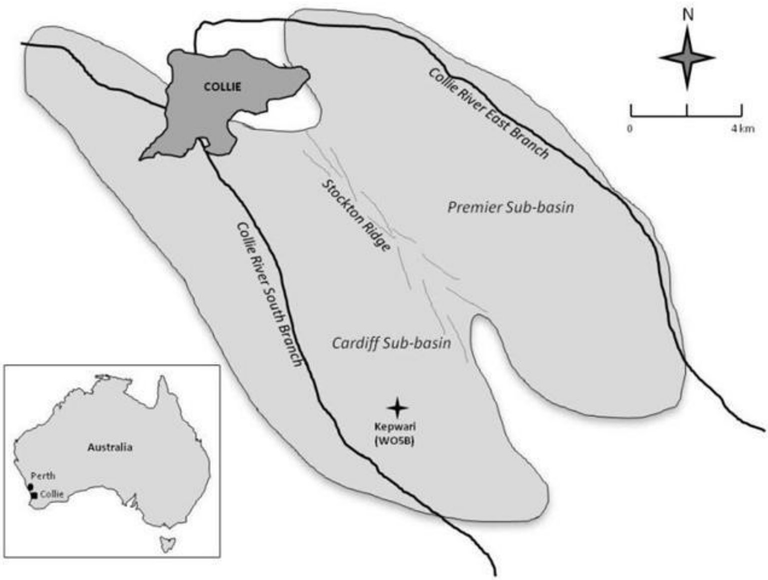

Figure 1 *Location of Lake Kepwari (asterisk) in the Collie Coal Basin in south-western Australia.*

Figure 2 *Aerial view of Lake breach point in October 2011 (a) and breach view from lake in March 2012 (b). Top of photos points north. (Digby Short, Clint McCullough). Arrows indicate the River breach point.*

Methods

Seasonal lake water column physico-chemistry profiles were taken with a Hydrolab Datasonde 4a multiparameter probe (Austin, USA) in a 2010–2011 unrelated project (Site 3 near the Lake centre), for monitoring following the breach in August 2011 (Sites 1 and 2, with Site 1 near the River breach) and in December 2011 and March 2012 (Sites 1–3, with Site 2 near the Lake decant). Profile data collected included temperature, pH, specific conductance (EC) and oxidation-reduction potential (ORP, platinum electrode).

Results and Discussion

Lake water column physico-chemistry profiles for 2010–2011 (pre-breach) and 2011–2012 (post breach) are shown in Figure 3. EC was very consistent in 2010 to 2011 (pre-breach) at around 3.15 mS/cm, before becoming slightly elevated during March 2011 to 3.3 mS/cm in the eplimnion, presumably due to evapo-concentration of these waters during summer stratification. During June 2010 to March 2011, Lake Kepwari showed complete mixing during winter months with thermal stratification presenting as a 15–18 m deep epilimnion during summer months.

CRSB flow is seasonal (dry in summer) with salinity from upper catchment secondary salinisation varying from fresh, to brackish at the start and end of winter flows before dilution by rain. Saline CRSB flow was used to rapid fill Lake Kepwari. However, the breach brought primarily fresh water into the lake resulting in a marked halocline. This halocline became more sharply defined and deepened to 10–15 m mixolimnion depth over the following months, although the difference between mixolimnion and monimolimnion waters decreased over time presumably due to evapo-concentration of surface waters and increasing salinities in the river inputs and also possibly due to partial mixing between mixolimnion and monimolimnion as the mixolimnion deepened. Groundwater inflow rate may have been unable to maintain lake water level during this time as had been found elsewhere (Santofimia and López-Pamo 2010) either due to low groundwater level or low rates of hydraulic conductance into the lake. Overall mixoliminion salinity increased from 2.1–2.5 mS/cm. Lake Kepwari surface water temperature increased in the six weeks following the breach from 15.5°C to 17.5–18.0°C (Figure), likely as a result of fine weather and solar warming.

Halocline persistence is not likely, given the mixolimnion is increasing in salinity and the likelihood of more saline flows at the start of the winter flows. It may however then reform once river flows become fresh. Use of a diversion weir in the breach point or river could be useful in enhancing the halocline or eliminating it. The halocline does present an opportunity to isolate the acidic pit lake waters and allow the surface waters to meet guideline levels.

During June 2010 to March 2011, Lake Kepwari pH ranged from 3.7–4.1 and exceeded recreational water quality guidelines of pH 5.0–9.0 (when weakly buffered) (NHMRC 2008) and 90% ecosystem protection guidelines of pH 6.5–8.5 (ANZECC/ARMCANZ 2000). pH was consistent between epilimnion and hypolimnion during this time. Following the breach, mixolimnion pH increased, ranging from 4.6–5.6, peaking in December 2011. It is likely that pH induced metal

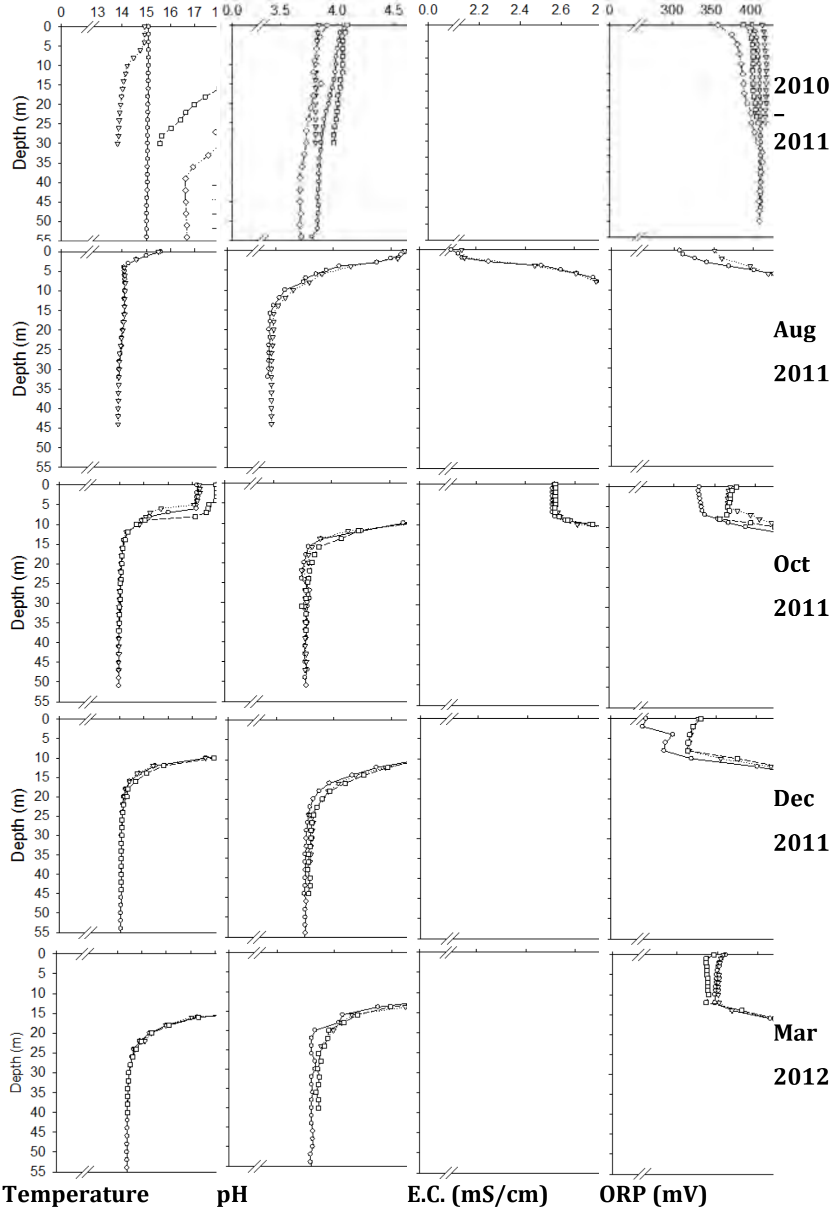

***Figure 3** Water column physico-chemistry profiles across depth in Lake Kepwari before and after the August 2011 river breach.*

precipitation, dissolved organic carbon chelation and neutralisation with higher pH river water (Welker & Streamtec 2001) would have decreased acidity and increased pH during this time. Given the relatively high volumes of water inflowing into the Lake following the breach, significant dilution may have also contributed to surface water pH increase.

During June 2010 to March 2011, ORP ranged from 360–420 mV and was slightly lower in surface waters during summer months. Following the breach, surface water ORP showed a decrease to 300–350 mV but an increase to 450–480 mV in the bottom waters. There was a further increase in the hypolimnion ORP in October to around 570 mV. It is unclear what caused this ORP increase, however, it was also seen, albeit to a reduced extent in the mixolimnion where ORP increased from mean 330 mV to mean 350 mV. Different to the other profiles, ORP varied between sites with Site 1 (closest to the breach) displaying ORP values around 50 mV lower than the other surface water sites. This may indicate low dissolved metal concentrations and ORP in the incoming river waters prior to mixing with higher ORP lake waters.

Conclusions

Although there was an initial decant of acidic waters to the river, however, it is likely that a planned flow-through could avoid this. Nevertheless, significant lake improvements in pH were observed following lake breach. Halocline development reinforced by thermal stratification as the season warmed maintained a less acidic and fresher/warmer layer over more acidic/colder waters representative of original lake water quality.

River flow-through remediated pH above recreational guideline pH values in the upper 10 m mixolimnion waters in which people would swim. However, studies of lake mixolimnion water quality for swimming for elevated metal and metalloid concentrations are required. The long-term stability of the halocline might also require reinforcing through select diversions from the river through the use of diversion weirs.

Further research includes monitoring at approximately three monthly intervals that coincide with end of seasons to monitor changes in stratification and pH. Additional monitoring will examine water quality and ecology in order to understand the benefits of the flow-through strategy in improving Lake Kepwari water quality and environmental values and as a closure strategy for both this and other pit lakes of the region/state.

In the first demonstration of this closure strategy in Western Australia, we propose that flow-through by seasonal connection of Lake Kepwari to the CRSB may result in permanent stratification and isolation of acidic pit lake waters at depth. Fresher and moderately alkaline mixolimnion water, essentially CRSB water, is more likely to enable the lake to meet regulatory requirements for recreational use. Further there is potential for the water quality of CRSB water, particularly for excess nutrients, to be enhanced by passage through the pit lake.

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