# Breach and decant of an acid mine lake by a eutrophic river: River water quality and limitations of use

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## Abstract

Surface and ground waters of catchments comprising mining resources often show elevated solute concentrations in baseline conditions due to their unique geologies which may complicate the interpretation of natural differences in regional water quality. Mining lease conditions often specify the use of ecosystem protection guidelines for regulating discharge water quality limits. We present a case study from Collie in south-western Australia, where breaching and subsequent decant of an acidic pit lake by a diverted eutrophic river identified the need for establishing site specific river water quality guidelines in a moderately disturbed catchment.

Following the breach of the acidic Lake Kepwari pit lake by the diverted Collie River in August 2011, water quality samples were collected at lake decant and other Collie River monitoring sites above and below the lake discharge on a daily basis for six weeks. Water quality results were compared to Australasian (ANZECC/ARMCANZ 2000) livestock drinking water guidelines, 90% ecosystem protection guidelines and recreational water quality and aesthetic guidelines.

Water quality results indicated no significant risk of toxicity to livestock drinking water during the period, however water quality at all sites sampled including a reference site above the discharge exceeded ecosystem protection guidelines for pH and Zn, and recreational water quality and aesthetic guidelines for pH, Fe, Al, Mn and TDS. We conclude that background concentrations in the Collie River are already slightly elevated in various solutes such that site specific water quality guidelines are recommended for future water quality analyses.

## Introduction

Due to operational and regulatory practicalities for many open-cut mines, pit lakes are common legacies after 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 minimizes long term pit lake liabilities and maximizes benefits to stakeholders and the environment, but is often neglected in mine closure planning (McCullough et al. 2009; McCullough and Van Etten 2011; Salmon and Jones 2012).

Pit lake hydrology at equilibrium is a key factor when considering pit lakes at closure (McbCullough et al. 2012).

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. Designing pit lakes as flow-through systems by connecting them to rivers is receiving more attention as strategy to achieve good lake water quality over long terms. Flow-through systems might not only maintain pit lake water quality but may also minimize 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.

The south west of Western Australia is regarded as highly biodiverse, with eight of the ten native freshwater fish found in the south-west endemic (Morgan et al. 1998). At least five species of native freshwater fish with limited distributions are also specifically found in the Collie region itself (Whiting et al. 2000). However, the biodiversity hotspot tag comes at a price, as these areas are listed for having the most endemic species and being the most threatened areas in the world (Myers et al. 2000; Malcolm et al. 2006).

The mining town of Collie is the center of the coal mining industry in Western Australia (Figure 1) (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 (Stedman 1988) and has resulted in the formation of at least 13 pit lakes that range from <1 to 100 ha in surface area, <10 to 70 m in depth, 1 to 50 years in age and in pH from 2.4 to 5.5 (Lund et al. 2012). These lakes differ in the extent of rehabilitation and water quality, yet 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. The overburden around the Lake edges was extensively revegetated with native plants and the lake flagged as a recreation resource (Evans and Ashton 2000). To further reduce wall exposure and acid production, the lake was rapid-filled by a diversion from the CRSB over three winters until 2005 (Salmon et al. 2008). Although the river water initially raised water pH to above pH 5, it subsequently declined to below pH 4 by 2011 and displayed elevated solute 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 $\times 10^6$ $m^3$, 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 authorized 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 CRSB 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.

As there are few examples internationally, this river breach event provided an opportunity to evaluate and understand the potential benefits of flow-through system as a pit lake closure strategy.

Complementing another study evaluating pit lake water quality (McCullough et al. 2012) this study collected data immediately post breach to track the changes in river water quality and how any changes might influence river end use values such as environmental, recreation and livestock drinking purposes.

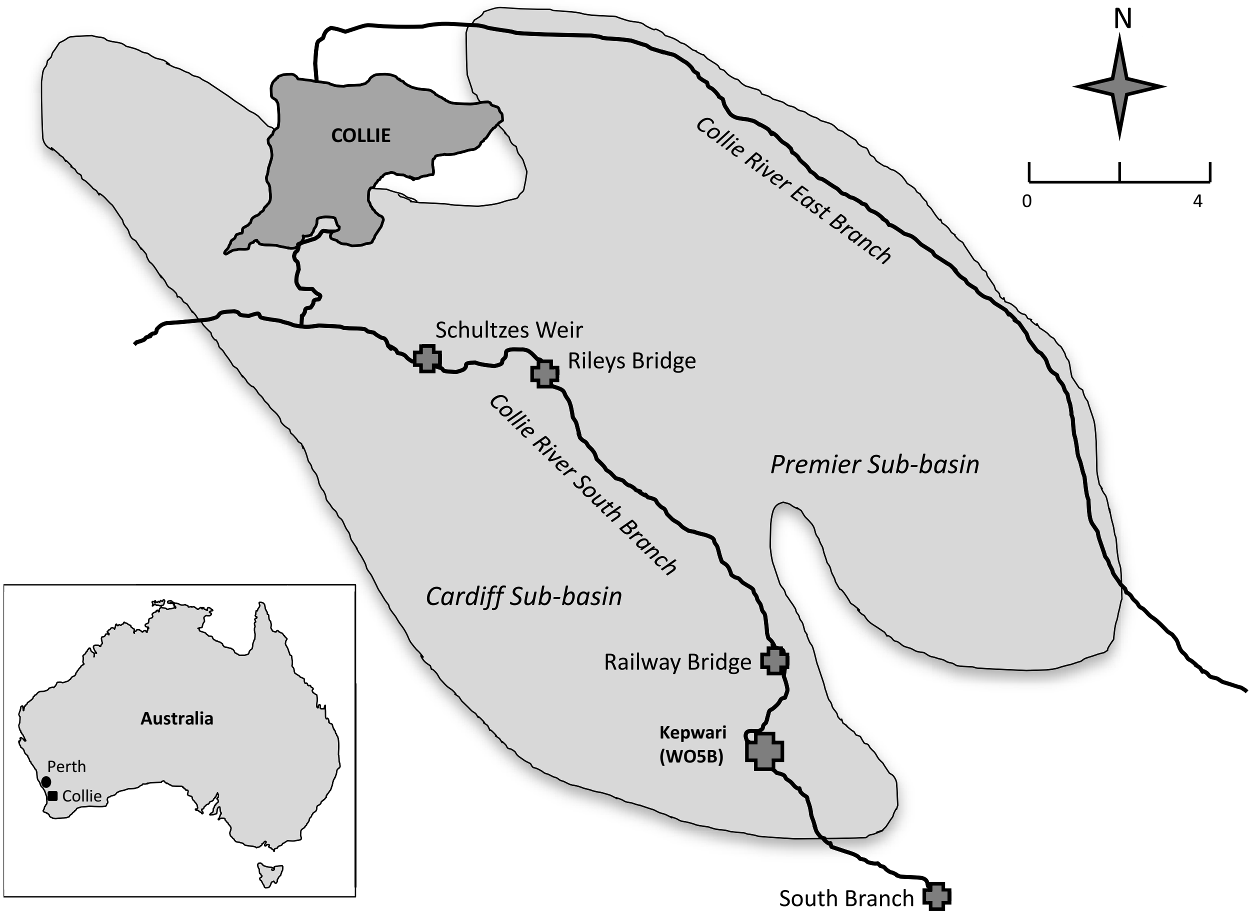


**Figure 1: Location of Lake Kepwari (large cross) in the Collie Coal Basin in south-western Australia. Water quality sampling sites above (South Branch) within (Lake Kepwari) and below (Railway and Rileys Bridges, and Schultzes Weir)**


**Figure 2: Aerial view of Lake breach point in September 2011 (left) and October 2011 (right). Top of left photo points south, right photo points north (Digby Red arrows indicate the River breach point)**

The key objectives for the current study were to:

- determine if the discharge from Lake Kepwari during the nine weeks following the lake breach and decant (23/8/2011 to 26/9/2011) exceed either Australasian (ANZECC/ARMCANZ 2000) guidelines for:
    - livestock drinking water;
    - 90% ecosystem protection;
    - recreational water quality and aesthetics, and,
- provide management advice to reduce the risk of the Lake Kepwari discharge to the Collie River environment
- ascertain how the inflow of circum-neutral (and likely alkaline) Collie River water has altered water quality and overall limnology of Lake Kepwari; in particular, if this inflow had mitigated low pH and other elevated metal concentrations as improvements of Lake water quality
- identify the impacts and benefits of river flow through at Lake Kepwari as a long term management strategy.

## Methodology

### Sampling locations and methods

Premier Coal environmental staff sampled the CRSB at monitoring sites above, within and below Lake Kepwari sites on a daily basis for six weeks from 23 August 2011 to 5 October 2011 when the CRSB ceased flow (Figure 1). At each location, samples were taken below the surface, from the bank from a fast flowing section. Monitoring of Zn and Al concentrations and other water quality parameters continued at a weekly interval until lake decant ceased and recovery to background water quality conditions could be demonstrated.

A single measurement meter (Hanna Instruments) was used to sample water quality at each CRSB site for pH. Water samples were also collected and laboratory analyses undertaken for dissolved Al, Fe, Mn and Zn concentrations. Water samples were filtered and then acidified with reagent grade nitric acid (1%) until analyzed for selected elements by Inductively Coupled Plasma Mass Spectrophotometry (ICP-MS, Varian). All water quality analyses followed standard methods (APHA 1998).

Water quality results were then compared to Australasian (ANZECC/ARMCANZ 2000) Livestock Drinking guidelines, and Recreation and Aesthetic water quality guidelines. Where guidelines were available, water quality results were also compared against guidelines for 80% Ecosystem Protection as the CRSB is described as "highly disturbed" (ANZECC/ARMCANZ 2000; Wetland Research & Management 2009). Where 80% Ecosystem Protection guidelines were not available, water quality results were conservatively compared against default 95% Ecosystem Protection guidelines (slightly disturbed ecosystems).

## Aquatic macroinvertebrates

Aquatic macroinvertebrates were collected as per Western Australian wetland sampling guidelines (Davis et al. 1999) from single sweeps along 10 m of the Lake and River littoral margins with a 250 µm mesh sweep net. Macroinvertebrate sorting began with a big-pick from the 2 mm fraction. The sample filtrate was then placed into a four-channel Bogarov tray and sorted by two passes with an Olympus SZ-STU2 stereo microscope. Macroinvertebrates from both the larger fraction CPOM sieving and from the smaller fraction sorting tray were also identified under this same microscope. In samples with likely more than 200 individuals, these abundant taxa were ignored in the first two-pass count. A 20% sub-sample of the remaining fraction (organic matter and crustacean taxa) was then two-pass counted again for these high abundance taxa.

**Figure 3: Sampling (left) immediately above in Lake Kepwari and (right) immediately below Lake decant in the CRSB on August 2011**

## Results

### River water chemistry

Water quality values recorded in the Collie River and Lake Kepwari during the six week monitoring period following the breach are shown in Figure 4. The legend lists sampling locations in succession, beginning at the most upstream reference site (South Branch), through to Lake Kepwari itself and ending at the most downstream reference site below Lake Kepwari (Schultzes Weir).

Lake Kepwari exceeded guideline levels for Primary Contact Recreation at all times except for two sampling events shortly after breach. pH values at all sites were also below the lower 95% Ecosystem Protection guideline of 6.5 for most of the sampling period apart from CRSB which rose above this guideline around two weeks after breach. A sudden decrease in pH occurred during the period 19 to 21

September in Lake Kepwari and at all downstream sites. It is unclear how this could have occurred unless inflows of River water through the breach point led to a short period of mixing resulting in the lake's hypolimnion water being mobilized into the upper water column. This lower pH water would then have been carried out of Lake Kepwari water and down through the Collie River. An alternative or complimentary explanation is that Lake water decanted back out through the breach point following River flow decline and resulting height decrease leading to a hydraulic gradient back to the main River stem. This lower pH water would then have been carried out of Lake Kepwari water and down through the Collie River. A rainfall event of 28 mm was recorded at nearby Muja Power Station #9738 on 18 September 2011 (BOM 25/03/2012), which supports this latter conclusion.

Dissolved oxygen (DO) was below Recreation and 95% Ecosystem Protection guidelines of 80% in all sites for much of the monitoring period, although DO was generally high in Lake Kepwari. DO decreased lower in the CRSB likely due to biochemical oxygen demand by decaying organic matter from allochthonous vegetation (Wetland Research & Management 2009).

Aluminum concentrations were well below Recreation and Stock Drinking Water guidelines at all sites and times. Although there are no 80% Ecosystem Protection guidelines for pH <6.5, Al concentrations at the majority of sites were also likely to contribute toxicity through increased monovalent Al ion concentration at these lower pH values (Neil et al. 2009). An unusually high Al concentration at Rileys Bridge on 19 September of 2.2 mg/l indicated a further source of Al input to the River above this point, most likely from another mine water discharge. Water quality results suggest that, although Al concentrations were slightly elevated in background conditions of the Collie River, in and downstream of Lake Kepwari had elevated Al concentrations.

Fe concentrations exceeded the Australasian Recreational and Aesthetic water quality and interim working Ecosystem Protection guidelines of 0.2 and 0.3 mg/l respectively at most sites during the sampling period. A noticeable spike in Fe concentration occurred at the South Branch on 14 September with a likely resulting subsequent spike at Railway Bridge downstream on the 19 September. Indeed, highest concentrations were from uppermost sites; including background concentration from the South Branch. These results indicated that reference concentrations are typically elevated in the Collie River and Lake Kepwari is likely not significantly influencing Fe concentrations downstream.

All sites exceeded Recreational and Aesthetic guidelines for Mn, with highest concentrations in Lake Kepwari. However, as with Al, an unusually high Mn concentration at Rileys Bridge on 19 September of 0.3 mg/l indicated a further source of Mn to the River; again, most likely from another, undetermined, mine water discharge to the river. South Branch reference site concentrations above the guideline indicate that Mn concentrations are already elevated in the CRSB. Nonetheless, Mn concentrations did not exceed 80% Ecosystem Protection guideline of 3.6 mg/l.

Zinc concentrations exceeded 80% Ecosystem Protection guidelines of 0.031 mg/l at all sites during the six week sampling period. Zn concentrations were highest in Lake Kepwari at around 0.4 mg/l and then doubled from background South Branch concentrations of around 0.08 mg/l to around 0.15 mg/l downstream after mixing with Lake decant water. Another spike in elevation at Rileys Bridge again indicated another mine water source of Zn above this site. Zinc concentrations did not come close to exceeding the Recreational and Aesthetic guideline of 8 mg/l or Livestock Drinking guidelines of 20 mg/l during the monitoring period.

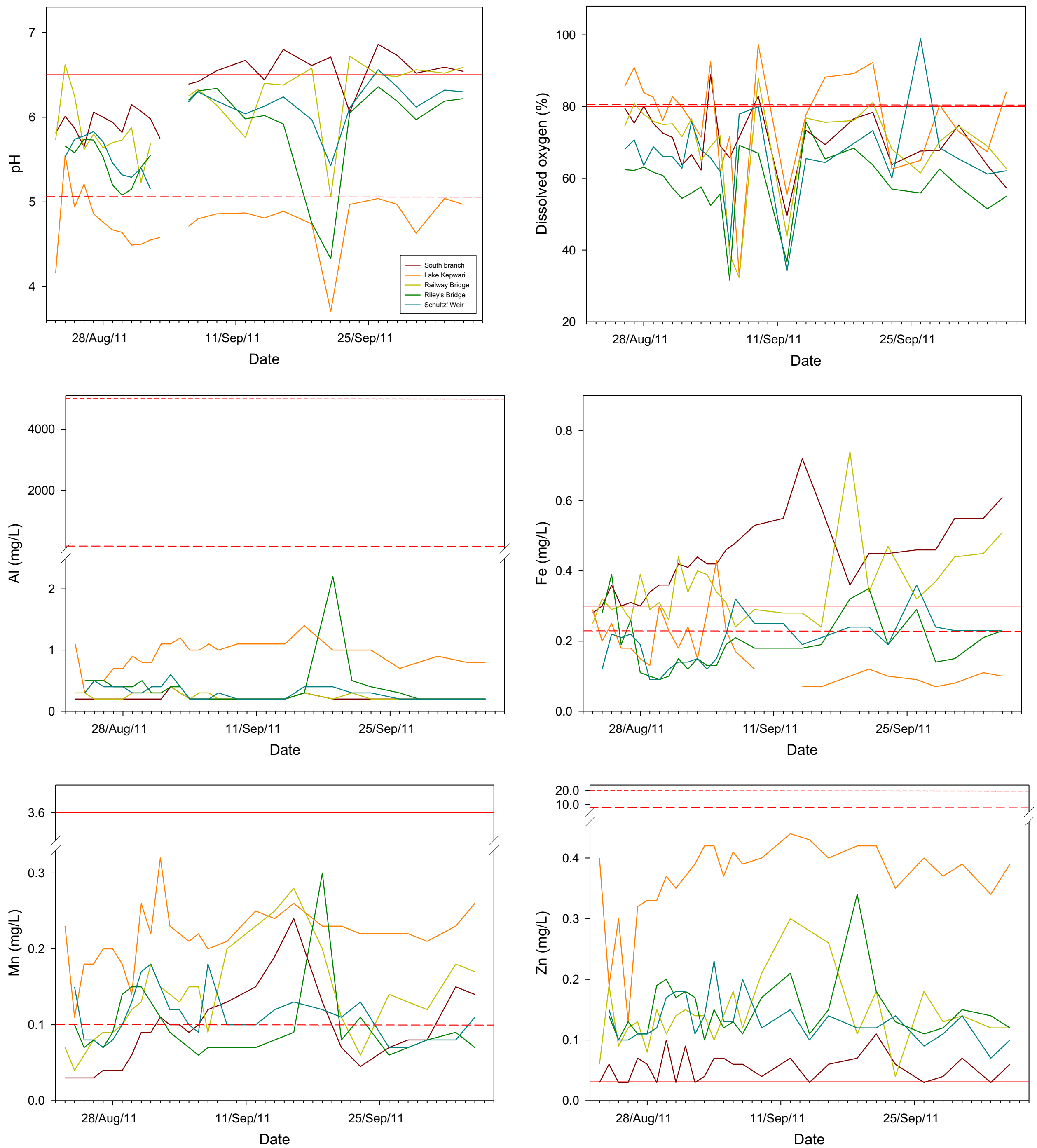


**Figure 4: Water quality in Lake Kepwari and the Collie River between 23 August and 24 October 2011 for selected parameters (ANZECC/ARMCANZ 2000)**

**Note:** Line gaps show missing data and red lines indicate guideline levels: solid lines Ecosystem Protection, dashed lines Primary Recreation and dotted line Stock Drinking Guidelines

## Aquatic macroinvertebrate assemblages

Aquatic macroinvertebrates are a popular biological group chosen to assess effects of aquatic pollution at the community scale (McCullough 2009). Internationally, analysis of benthic macroinvertebrate communities has been the foremost tool for biological assessment of aquatic ecosystems due to the availability of good taxonomy and extensive literature of pollutant effects (Norris and Hawkins 2000). Macroinvertebrates are also often the most speciose community in aquatic ecosystems with typical characteristics of relatively long life cycles, ecological relevance, low motility and comparatively simple identification are good qualities for assessing the impacts of pollutants.

Summary aquatic macroinvertebrate sampling results are presented in **Error! Reference source not ound.**. Aquatic macroinvertebrate taxa richness and abundance increased immediately below the breach point to immediately below the Lake Kepwari decant, although this was dominated by amphibious Collembolla that are more sensitive to habitat than to water quality. A similar increase in Ostracod zooplankters immediately below decant point was also likely more due to this group of crustacea responding to the sandy beach substrate found here rather than water quality itself. Nonetheless, this group is moderately sensitive to poor water quality (Chessman 2003) and their presence here demonstrates that little ecological impact occurred below the discharge. Similarly, elevated numbers of Cyclopoid zooplankter copepods immediately below decant point immediately below the breach indicated reasonably good water quality there where they were likely feeding on algae and other organic particles in River eddies. This increase in macroinvertebrate taxa richness and abundance was likely due to better habitat of slower water in this lower River where the channel was less constrained and to coarser substrate. It does, however, indicate that the potentially degraded water quality of this site was not having a significant impact on macroinvertebrate assemblages. Lake Kepwari showed poor aquatic macroinvertebrate biodiversity and abundance, as other studies have also previously found (McCullough et al. 2010) with assemblages dominated by robust and cosmopolitan species such as dytiscid beetles and notonectid bugs which are known to be tolerant to many poor water qualities.

**Table 1: Aquatic Macroinvertebrate Assemblage in Collie River and Lake Kepwari on 25 August 2011**

| Site | Taxa richness | Abundance |
|---|---|---|
| Immediately below breach point/above decant point | 12 | 355 |
| Immediately below decant point | 23 | 449 |
| Lake Kepwari northern shore | 2 | 3 |

## Conclusion

There was no evidence that the breach and subsequent decant of lake water from Lake Kepwari presented any significantly increased risk to stock drinking water in the Collie River South Branch below the breach point during the six weeks of water quality sampling. Although there was an initial decant of acidic waters to the CRSB below the lake with little dilution afforded by the River, a planned flow-through (e.g., via a weir) could mitigate or even completely avoid this by only decanting as a controlled flow to allow for dilution of Lake AMD water by the CRSB.

Water quality at all sites sampled exceeded ANZECC/ARMCANZ (2000) 80/95% Ecosystem Protection guidelines for pH, DO, Fe and Zn concentrations, and ANZECC/ARMCANZ (2000) recreational water quality and aesthetic guidelines for pH, DO, Fe, and Mn. Although there are no Ecosystem protection guideline values for Al, research studies indicate this is likely to be toxic to some aquatic biota at the pH values encountered, albeit with concentrations still well below Livestock and Recreation guidelines.

Although upstream Zn and Al concentrations were elevated in the Collie River, downstream sites showed Al, Mn and Zn concentrations likely elevated by the lake Kepwari breach and decant. However, the regular exceedance of water quality guidelines also by the reference South Branch site indicates that Collie River background concentrations were already elevated for many of these parameters. Although there are no known mine influences above this point, there are known catchment activities that have degraded water quality through eutrophication such as farming (Wetland Research & Management 2009) and salinisation through forest clearance (Tingey and Sparks 2006). The geology of the Colie Coal Basin is also likely to have influenced water quality as is typically does with mine waters in other mining regions (Castendyk 2009) as increased solute concentration for some elements in a manner not encountered in most other catchments in Australasia.

Aquatic macroinvertebrate assemblages were extremely depauperate in Lake Kepwari, however, taxa richness and abundance significantly increased from immediately below the breach point to below the decant point indicating that the decant water was not likely having a significant impact upon aquatic invertebrates of the Collie River at these sites.

In conclusion, we recommend that:

- River water quality monitoring continue during any discharge from Lake Kepwari to determine any risk to CRSB ecosystem, livestock drinking and recreation values;
- sediment sampling be undertaken along the Collie River to determine whether fine sediments downstream from the lake Kepwari breach and decant have become elevated in metal concentrations (in particular, Zn) and pose any risk of toxicity to the downstream ecosystem;
- due to the Collie River being slightly elevated in a range of water quality parameters, for future water quality analyses Collie River specific water quality guidelines should be developed for the site based upon a historical reference site e.g. upstream data; and,
- Lake water quality monitoring should continue in order to inform of the benefits of the River inflow to improving water quality and environmental values of Lake Kepwari in its own right as a closure strategy for both this and potentially other pit lakes of the region.

In this first demonstration of this closure strategy in Western Australia, we consider 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 Lake surface 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 AMD removal of excess nutrients such as P (Kleeberg and Grüneberg 2005), to be enhanced by passage through the pit lake (McCullough et al. 2012).

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