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Figure 1. 'Blue Waters' lake (Collie) formed in 1962.

Australia's mining boom leads to a boom in new lakes

Australia is a major producer for many of the world's minerals and mining is the most significant industry contributing to the Australian economy (Mudd, 2007). However, a growing scale of mining continues to leave legacies of large open-cut operations with a depth that ensures part of the pit is often positioned below local groundwater tables (Radhakrishnan *et al.*, submitted). Once dewatering operations cease, these voids can form pit lakes with water from surface sources and groundwater returning to pre-mining levels. Quality of pit lake water can vary considerably, depending on surrounding geologies and exposure of material previously buried. Acid mine drainage (AMD) is an example where exposed materials are oxidised and release acidity resulting in pit lake waters of low pH and typically elevated concentrations of heavy metals (Banks *et al.*, 1997). Conversely, such acidic lakes have extremely low concentrations of carbon and phosphorus (Castro & Moore, 1997). However, where remediation can achieve suitable water quality these pit lakes may become a valuable asset to Australian communities and the environment (McCullough & Lund, 2006).

Low acidity mine lakes

Coal mining in southern Western Australia has produced pit lakes that range in surface area from <1 to 10 ha, depths from <10 to 70 m and age from 5 to 50 years (Lund & McCullough, 2008) (Figure). Although Collie

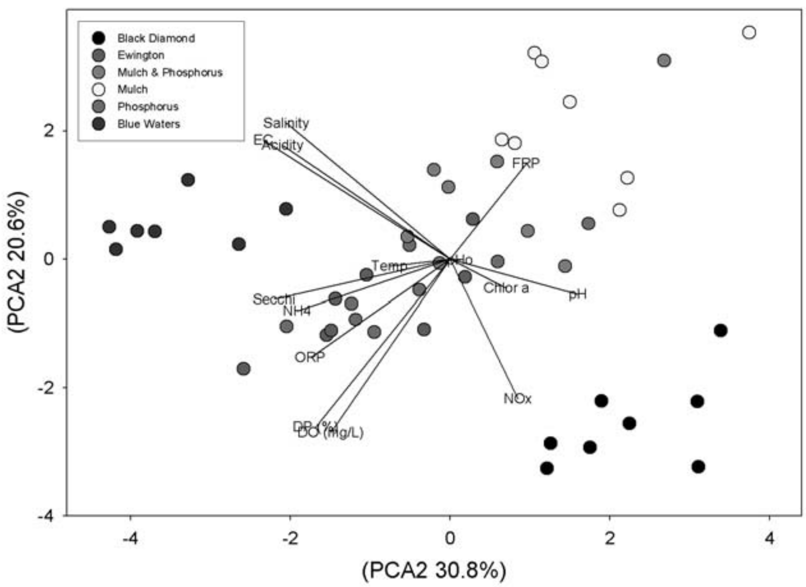

Figure 2. Effect of carbon and phosphorus amendments on mine pit lake water quality over 7 months. Blue Waters Lake pH is lowest at 4.1, Lake Ewington is pH 4.3 and Black Diamond pH is highest at 5.5.

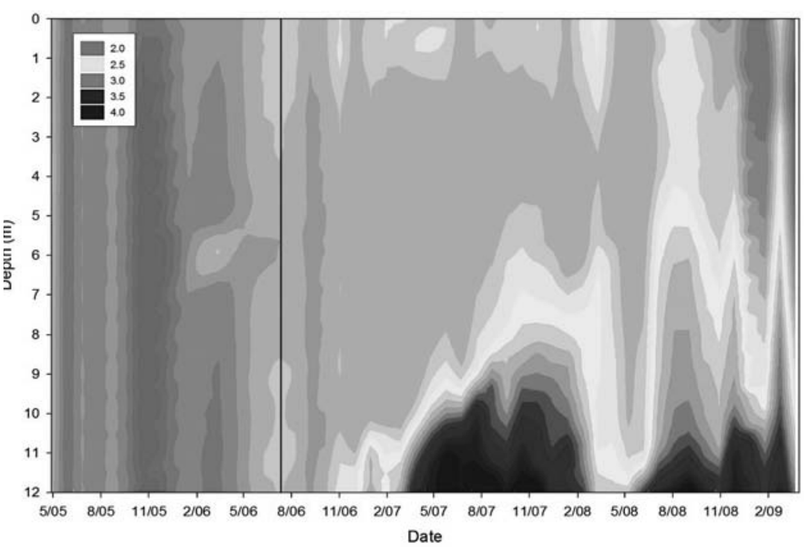

Figure 3. pH changes in northern Australia GAEW pit lake from May 2005 to March 2009. The black line indicates the beginning of organic dosing.

coal pit produces low amounts of acid mine drainage, low natural alkalinity produces pH as low as 3.5 in some pit lakes. Low pH is accompanied by low metal concentrations in pit lake waters, except for aluminum, which at high concentrations is often a toxic species (Neil *et al.*, submitted). Analysis of historic Collie pit lake water quality data from 1995 to present has shown that in the absence of significant surface acidity inputs, acidity within the pit lakes slowly declines but without a commensurate change in pH. Increases in pH are only due to inputs of circum-neutral groundwater or surface waters. Experimental water quality remediation by additions of organic matter and phosphorus direct the lakes to a different water quality evolution trajectory from that of natural remediation processes (Figure 1).

In order to minimise wall exposure and subsequent acid production, a new pit lake, Lake Kepwari, was rapidly filled by a diversion from the Collie River over three winters until 2005 (Oldham *et al.*, 2009). The volume of Lake Kepwari is now 24 GL, with a maximum depth of 65 m and surface area of 10 ha. The proposed end use for this pit lake was contact recreation such as water skiing (Evans & Ashton, 2000). However, although the river water initially raised water pH, the pH has now decreased to 4.8 with elevated metal concentrations (Salmon *et al.*, 2008). This pit lake is good example of how government-supported rehabilitation, lacking in understanding of ongoing limnological acidity-generating processes, has resulted in water quality unsuited to the proposed end-use.

High acidity mine lakes

Garrick East pit lake (North Queensland, north-eastern Australia) is located within the semi-arid tropics and was mined during the 1990s. The lake has a pH of 2.4 with such high concentrations of dissolved metals and sulphate that they form crystals of epsomite underwater. Following successful microcosm pilot studies (McCullough *et al.*, 2006; McCullough *et al.*, 2008b), the lake was split with an earthen barrier and one side was remediated by dosing the 70 ML treatment lake section with dried sewage sludge (60 t), liquid sewage sludge (3,200 t) and municipal green waste (980 t). Water quality was monitored in both pre- and post-dosing in the treatment section and in three control pit lakes over the last few years (McCullough *et al.*, 2008a). Following organic additions, pit lake water chemistry indicated large pH increases through internal sulphate reduction processes. Nevertheless, pH declined again after 12 months of increase and subsequently it recovered and declined again. This decline is thought due to ongoing surface water acidity inputs and water column mixing during heavy cyclonic rainfall events. Nevertheless, this study suggests that addition of low-grade organic materials show promise for remediation of strongly acidic mine waters, particularly in a tropical climate.

Planned formation of pit lake environments worldwide is still at an early stage of development and actual realisation of these often significant water resources is even less frequently explored. After more than half a century of the first large flooded mining pits occurring, the question how to utilise and manage pit lakes remains a challenge for the Australian mining industry, governments, and communities.

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