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Technical Communication

Opportunities for Sustainable Mining Pit Lakes in Australia

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Abstract. Due to operational and regulatory practicalities, pit lakes will continue to be common legacies of mine lease relinquishments. Unplanned or inappropriate management of these geographical features can lead to both short- and long-term liability to mining companies, local communities, and the nearby environment during mining operations or after lease relinquishment. However, the potential for pit lakes to provide benefit to companies, communities, and the environment is frequently unrecognised and yet may be a vital contribution to the sustainability of the open-cut mining industry. Sustainable pit lake management aims to minimise short and long term pit lake liabilities and maximise short and long term pit lake opportunities. Improved remediation technologies are offering more avenues for pit lakes resource exploitation than ever before, at the same time mining companies, local communities, and regulatory authorities are becoming more aware of the benefit these resources can offer.

Key words: AMD; Australia; end use; mine waters; pit lake; sustainable mining

Introduction

Being a finite abstraction, "sustainable mining" is something of an oxymoron for what is inherently unsustainable activity (Mudd 2005). Nevertheless, in an era of increasing recognition of environmental and social damage from an ever-growing scale of mining coupled with increasing corporate social conscience for these activities, the mining industry usually works to reduce operational risk and retain its social licence to mine the community resource through a variety of strategies. Many of these strategies are focused around the concept of sustainability, including creating sustainable livelihoods (employment, community development, and infrastructure), optimising resource use, and final closing of mining operations in a manner that minimises social and environmental harm and yet retains future options for the lease (BHP Billiton Plc 2005; Rio Tinto Plc 2005). Although understandings do vary (Mudd 2005), sustainable mining commonly incorporates "the evaluation and management of the uncertainties and risks associated with earth resource development" (Meech 1999). This sustainability definition also fits well with the understanding of most government authorities concerned with the regulation of environmental and social impacts of mining (Mudd 2004). As a result of this regulatory focus, sustainability of mining leases is often solely concerned with minimising the immediate and long term risks to all stakeholders concerned (e.g. the social and ecological environment surrounding the mine).

One potential legacy of open-cut mining is the mining pit(s) left after rehabilitation operations are completed. Some of these pits are constructed either in part, or in whole, below the surrounding natural ground water levels. As a consequence, once dewatering operations stop and surface and ground waters equilibrate, these pits may form pit lakes (Castro and Moore 1997). The pit lake water may be contaminated with elevated concentrations of heavy metals and/or acid mine drainage (AMD) (Banks et al. 1997). The pit lake may act as a ground water "sink" under low rainfall/high evaporation climes, increasing in salinity whilst lowering surrounding ground water levels (Commander et al. 1994). Alternatively, in higher rainfall environments, clean surrounding ground water can be contaminated as it passes through the pit lake.

Regulators generally prefer complete backfill of pits with waste rock, tailings and/or operation wastes to reduce ground water interaction and acid production (Johnson and Wright 2003). However, although backfilling may be considered a simple solution to the formation of pit lakes, it is often not cost effective or even desirable. In fact, complete backfills are rare due to the high expense involved and potential contamination issues associated with the fill material. Nonetheless, pit lakes may quantitatively contribute more to mine water pollution than tailings and waste rock dump leachates arising from the same mining lease (Younger 2002).

There are an estimated 1,800 open-cut pits in Western Australia alone, ranging from one or two hectares in area and a few meters deep to the increasingly large modern pits of several square kilometres in area and hundreds of meters deep (Johnson and Wright 2003).

These pit lakes have few natural counterparts in the Australian landscape where natural lakes tend to be more shallow and seasonal in nature. Therefore, mining pit lakes represent a novel addition to the aquatic resources of the region. The nearest ecological counterparts of these new lakes are reservoirs, but the cross-sectional profiles of reservoirs are different and by their nature have reasonable turnovers of the water in them (through high capture and exploitation rates). Especially in dry continents such as Australia, and also as an aspect of water-related issues of the mining industry internationally, pit lakes may be seen as a model of the challenges of management of the wider water resource crisis facing the global community today (Brown 2003).

Environmental and Social Risks of Pit Lakes

Like most developed countries and states, performance bonds are held by government pending appropriate rehabilitation and final relinquishment of mining leases. For example, currently the Western Australian mining industry has around $350 million worth of unconditional performance bonds held against it by the State Government on grounds of environmental performance (Western Australia Chamber of Minerals and Energy 2004). However, in many states, these performance bonds occur in a regulatory environment with no specific water quality guidelines for managing pit lake risks [e.g. Nguyen (2006)], even though mine waters have been internationally identified as the greatest off-site risk of mining to local communities and their environment (Younger 2002), and that water use at many of Australia's remote, arid locales can represent a large proportion of the local supply (Brown 2003).

There are clearer standards for managing the vast masses of waste rock that may arise in the excavation of an open-cut pit and which may be the single largest cause of ecological impacts in a pit lake (Mudd 2005). However, at present, there are only regulatory guidelines available for natural lakes, which may be overvalued, or otherwise inappropriate analogues to pit lakes. Consequently, regulation of pit lake water quality in much of Australia is made on case-by-case assessments and pit lake water quality is regulated according to either specific end-use requirements, or safety of the surrounding environment (Evans et al. 2005).

During active mining operations, pit water management is typically well understood and regulated (Johnson 2003). However, following mine closure, the management and relinquishment requirements for developing pit lakes are far less well understood by either mining companies or their regulatory bodies (Pilkey 2003). As a result, pit lakes tend to have limited biological activity and chemical interactions dominate (Castendyk and Webster-Brown 2006). Our experiences researching pit lakes in Australia suggest that even after 50 years, ecological processes are often still very restricted (Lund et al. 2006; McCullough and Lund 2006).

Pit lakes present many significant health and safety issues for both the mining company and adjacent human and wildlife communities for many years following cessation of mining operations (Doupé and Lymbery 2005). For example, pit walls can be unstable and can become more so during lake filling. Pit lakes tend to have a low surface area to depth ratio compared to natural lakes and have steep sides. This steepness may produce risks for lake users such as local communities, live stock, and wild life where there is a risk of falls from the pit "high walls", or for swimmers where there is a risk of drowning with the limited shallow margin (Figure 1).

Wildlife drinking from pit lakes may ingest contaminated water, which could cause severe trauma or and/or eventually death. Acidic pit lake water may also remove natural oils from the feathers of waterfowl leading to their deaths through drowning or exposure (Woodbury 1998). Bioaccumulation of elevated heavy metals may be of concern to wildlife and communities utilising pit lake fisheries (Evans et al. 2000).

Although the impacts of mining has not yet been specifically examined, land use change by humans has long been recognised as a causative factor in the outbreak of mosquito-borne diseases (Norris 2004). By increasing their breeding habitat, pit lakes may also harbour waterborne diseases and their vectors,

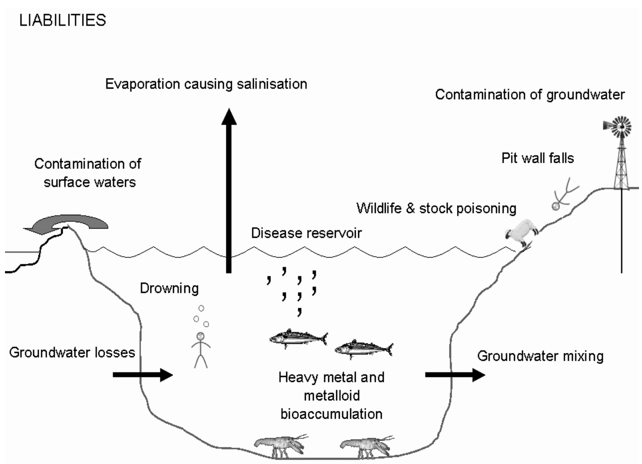

Figure 1. Potential liabilities of pit lakes to communities and the environment

as mosquitoes (Pilbara Iron Ore Environmental Committee 1999). For example, mosquitoes of the *Culex* genus, some of which are capable of transmitting Ross River fever and Australian encephalitis, have been found in abandoned pit lakes of the Collie region (Lund et al. 2000). As pit lakes become remediated and increase in nutrient status over time, they may become even more attractive to laying adult mosquitoes (Leisnham et al. 2005, 2006) and may consequently form more significant sources of disease-carrying mosquito vectors in historical mining regions (Johnson and Wright 2003).

Some pit lakes e.g., the western desert's Pilbara, Goldfields, etc. suffer problems associated with hypersalinity. In areas with high evaporation and/or low precipitation and low ground water flow rates, hypersalinity may be caused by saline ground water being drawn into these lakes through evaporation (Johnson and Wright 2003). Saline ground water intrusion may result in long term increases in pit lake salinity and lowered ground water levels (Commander et al. 1994). In addition to direct loss of habitat through reduced ground water levels, deteriorated ground water quality may contaminate underground (stygofauna) biotic communities (Environmental Protection Authority 2005), or overflow into surface water environments utilised by local communities and endemic biota (Kuipers 2002; Younger 2002). Nevertheless, ground water quality deterioration by mining has been considered inconsequential in some areas that are deemed only useable for mining purposes (Taylor et al. 2004).

Conversely, in higher rainfall areas such as Collie in Australia's southwest, or in the high rainfall area of the "Top End" of the Northern Territory, lake inflow exceeds evaporation, resulting in a flow of water out of the lake into the ground water. Contaminants in these pit lake, such as heavy metals and low pH, may be transported into the ground water and discharge downstream (Mudd 2002b). Contamination of through-flow ground waters may have profound consequences for natural and human communities in arid regions of Australia that are almost entirely dependent on ground water (Mudd 2002a).

During active mining operations, pit water management is typically well understood and regulated (Johnson 2003). However, following mine closure, the management and relinquishment requirements for developing pit lakes are far less well understood by either mining companies or their regulatory bodies. Remediation by fast-filling through river diversion may fill pit lakes in a timescale of only years (Schultze et al. 2002, 2003), while ground water-filled final pit lake levels, and chemical and biological conditions may take centuries to reach equilibrium levels (Johnson and Wright 2003).

Predictive geochemical modelling of pit lake water chemistry can be a powerful tool for the preparation and ongoing management of final hydrology and water quality of these lakes (Castendyk and Webster-Brown 2006). However, the majority of predictive models in current use and development are adapted from research into natural lakes or reservoirs. Although these systems may share some of the same physical and chemical complexes of pit lakes, as aforementioned, pit systems differ in many fundamental ways which may lead to either inaccuracies or simply lack of confidence in prediction and consequent acceptance of modelling conclusions (Wright 2000).

Furthermore, although the primary use of predictive water quality models is to satisfy regulatory agencies, water quality is only one of the issues needing consideration. Health and safety issues, such as final pit lake water heights and interactions with surrounding water bodies, flood risks, and possible disease vectors, may remain undefined.

Nevertheless, although pit lakes may present risks to the environment and local communities through both their structural safety and water quality issues, pit lakes typically remain the cheapest, and often, most practical option for relinquishment of many open-cut leases and will continue to be formed across Australian and the world as mining companies cease their operations.

Sustainable Pit Lakes

Probably the most commonly quoted definition of sustainability for human societal activities as a whole, and one that is widely accepted by mining companies and regulatory authorities, is that "sustainable development is development that meets the needs of the present without compromising the needs of future generations to meet their own needs" (World Commission on Environment and Development 1987). However, in the mining industry, sustainability post mining is typically only defined as leaving no ongoing environmental and social impact from mining operations [e.g. O'Reilly (2003)]. Consequently, a better definition of mining sustainability that also encompasses benefits that mining legacies such as pit lakes may offer may be "minimising long term risks of pit lakes, whilst maximising both short and long term benefits, for all stakeholders". Pit lakes can provide economic, health, welfare, safety or aesthetic benefits to the community (Doupé and Lymbery 2005; Johnson and Wright 2003) (Figure 2).

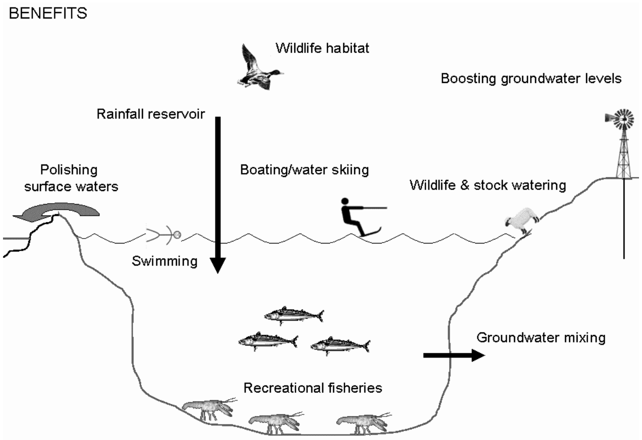

Figure 2. Potential benefits of pit lakes to communities and the environment

In contrast to the risks and liability that pit lakes may represent to companies, adjacent communities, and the environment, pit lakes may also represent significant benefits, frequently untapped in the pursuit of lease viability and profitability (Table 1). As an example, Australia has the lowest rainfall of any continent and water has been recognised as a limiting and highly valuable resource (Smith 1998). Some of these pit lake opportunities, such as recreational swimming, are organic developments of their communities and, whilst unrecognised and unregulated by local authorities, are already well-established in many arid mining regions with reasonable pit lake water quality (pers. obs.).

Other pit lake opportunities will require specific and direct support from mining companies and regulatory authorities, and the willingness and acceptance of local communities, who will often be a direct beneficiary of such opportunities, e.g. aquaculture and irrigation, direct contributions to local business ventures, employment, and associated income (Doupé and Lymbery 2005).

A widely accepted definition of health takes the potential benefits of a pit lake legacy even further: "health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (World Health Organization 1946). Like any significant geographical feature, pit lakes represent focal points to remote Australian mining communities, in an otherwise featureless landscape. These focal points also serve to engender the psychological benefit of a sense of place in addition to the more tangible end use benefits (Kozlowski and Hill 2000).

Water Quality Issues

The substantial cost of finding, developing and accessing water sources has meant that the mining industry has become adept at optimising water consumption through recycling and development of technologies that minimise water use (Western Australia Chamber of Minerals and Energy 2004).

Nevertheless, many domestic mining operations are located in arid areas across Australia and are still restricted by the availability of water resources. Pit lakes represent a huge potential source of water for mining companies and their communities and the local environment. Although pit lake opportunities may be desirable, a fundamental constraint is frequently the existing or future pit lake water quality

Table 1. Examples of Australian pit lake end uses beneficial to mining companies, their local communities, and the natural environment, and an Australian example of that end use (end use categories, after Doupe et al. 2005).

Beneficial end use type	Example of end use opportunity taken	Example location (primary resource mined) and reference
Aquaculture	Assorted in-fish and marron	Granny Smith Mine, Goldfields (gold) Wesfarmers, south-west Western Australia (coal) (Otchere et al. 2004; Syddell 2004)
Industry water	Reduced salinity water for haul road dust suppression	Collinsville Coal Project, North Queensland (coal) (McCullough et al. 2006)
Irrigation	Mango horticulture	Enterprise Pit, Northern Territory (gold) (Pine Creek Community Government Council 2003)
Mitigation wildlife conservation	Constructed wetlands for waterfowl	Capel Lakes, south-west Western Australia (mineral sands) (Doyle and Davies 1999)
Potable water source	Remote mining town supply	Wedge pit, Goldfields (gold) (Australian Labor Party, 5 Feb, 2004)
Recreation and tourism	Boating, water skiing, bathing	Historic and new Collie pit lakes (coal) (Lund 2001; Chapman 2002; Western Australian Tourism Commission 2003)
Research and education	Formal and informal education opportunities	Most pit lakes have this capacity
Sacrificial	Saline river first-flush storage	Chicken Creek, southwest Western Australia (coal) (Bills 2006)

(Doupé and Lymbery 2005; Johnson and Wright 2003). The science of many remediation strategies is well-established and there is a broad range of remediation technologies to select from. Remediation, sometimes only required in the first years following pit flooding (Younger 2000), is also increasingly available for other water quality issues as international interest in pit lake legacies continues to grow and people recognize that there are untapped potential pit lake benefits (Klapper and Geller 2002).

Conclusions

Pit lakes will continue to contribute to the legacy of the mining industry across the globe. However, knowledge of pit lake science and the interaction and utility of these features for adjacent communities is often inadequate for much of Australia's differing climatic, geological and social regions. As a result, pit lake currency and prediction of some of these regions are particularly poorly understood, especially in the dominant mining areas of the Australian semi-arid and arid interior.

It follows that a pit lake management view that only considers minimisation of liability may miss significant opportunities for maximising the benefits that these water sources can offer; both now, during mine operation and in the future after the mine lease has been relinquished. Although beneficial end uses for pit lakes have potential for environmental impacts and an actual or perceived impact upon human health and safety (Doupé & Lymbery 2005), end use opportunities and benefits extend beyond the mining company to the local community and also to the environment (Noronha 2004).

There has been growing recognition in the last decade of the need to plan for mine closure; increasingly even before mining operations begin (Brown 2003). Although mining companies and their local communities will be clearly oriented primarily towards mining operations as the major industry in the area, an overly narrow view of mining being the only successful use for the lease land may fail to recognise that pit lakes may be a *boon* to the post-mining community. Further, communities benefiting from pit lakes are also more likely to support lease relinquishment than those that are left with a neutral situation, or even worse a liability remaining from their local pit lakes. Water quality may initially, or eventually, restrict many of end use opportunities. However, current and emerging technologies may enable remediation of these mine waters to standards whereupon they can then be used for many of these beneficial end uses. Nevertheless, in order for pit lakes to be a viable relinquishment option for a company, community and the environment, a management strategy for the development and final form of the pit lake must be considered well before rehabilitation operations have begun (Evans and Ashton 2000; Evans et al. 2003). Consequently, pit lakes need to be planned for (Evans and Ashton 2000; Evans et al. 2003), not only to minimise risks, but also to maximise these opportunities for benefit.

In conclusion, for best sustainable management of lease resources for companies, communities and the environment, pit lake management should be more than simply parochial meeting of regulatory criteria to lease relinquishment. Assessing current and potential end uses for pit lakes is an important, yet little-recognised way, in which significant benefits to all three of these stakeholder groups can be made over an indefinite long-period of time, and in a mutually beneficial fashion.

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