PIT LAKE SUSTAINABILITY IN AUSTRALIA – WHAT IS IT, AND HOW DO I GET IT?

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Abstract

Due to operational and regulatory practicalities, pit lakes will continue to be legacies of many open-cut mining lease relinquishments. Unplanned or inappropriate management of these significant geographical features may lead to a short-term liability to all stakeholders during mining operations, or to ongoing liability to the local community and environment following 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. Improved remediation technologies are offering more avenues for pit lake end use than ever before, at the same time mining companies, local communities and regulatory authorities are also becoming more aware of the benefit these water resources have to offer. Sustainable pit lake management aims to better minimise short and long term pit lake liabilities, and yet also to maximise short and long term pit lake opportunities as well.

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Introduction

Being a finite abstraction, “sustainable mining” is something of an oxymoron for an inherently unsustainable industry for the locally affected area (Mudd, 2005). In an era of increasing environmental and social damage through an growing scale of mining, and increasing 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, primarily focused around the concept of sustainability. These direct or indirect strategies include creating sustainable livelihoods (employment, community development and infrastructure), optimising resource use, and closing operations in a manner which minimises social and environmental harm and yet also retains future options for the lease as well (BHP Billiton Plc, 2005; Rio Tinto Plc, 2005). Although understandings do vary (Mudd, 2005), one common definition which is typical of that of the mining industry and its regulators is that sustainable mining is “the evaluation and management of the uncertainties and risks associated with earth resource development” (Meech, 1999). This definition fits well with the understanding of most government authorities concerned with mining activities, in that their foremost involvement with such activity is regulation of environmental and social impacts of mining (Mudd, 2004). As a result, sustainability of mining leases is often solely about *minimising* the immediate and long term *risks* to the stakeholders concerned.

A potential legacy of open-cut mining is the mining pit(s) left after operations are completed. Some of these pits are constructed either in part or in whole, below the surrounding natural groundwater table levels. As a consequence, once dewatering operations stop, these pits may form pit lakes as surface and groundwaters equilibrate (Castro and Moore, 1997). Some mine measures may cause contamination of the filling pit lake through elevated concentrations of heavy metals and/or ARD (Acid Rock Drainage) (Banks et al., 1997). The pit lake may act as a groundwater “sink” under low rainfall high precipitation climes increasing in salinity whilst lowering surrounding groundwater levels (Commander et al., 1994). Alternatively, higher rainfall environments may lead to a “flow-thru” system in which clean groundwater is contaminated as it passes through the pit lake.

Generally preferred by regulators to help resolve many liabilities produced by these pits, complete backfills of pits with waste rock, tailings and/or operation wastes may prevent such groundwater interaction issues and keep acid producing and other toxic geologies in restricted environments (Johnson and Wright, 2003). Nevertheless, although backfill may be considered a simple solution to the formation of pit lakes, it is often not cost effective, or sometimes even desirable. For example, many historically new pits are often of too large a scale to be readily backfilled, or backfill geologies may risk contamination of groundwaters. In the event of backfill not occurring, mining pit lakes may quantitatively contribute more to mine water pollution than do tailings and waste rock dump leachates arising from the same lease (Younger, 2002).

Largely as a result of this large expense, there are an estimated 1,300 open-cut pits in Western Australia alone, ranging from one or two hectares in area and a few metres deep, to the increasingly large modern pits of several square kilometres in area and hundreds of metres deep (Johnson & 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. 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 rates and exploitation rates). Nevertheless, these pit lakes represent a novel addition to the aquatic resources of the nation. Consequently, management of these substantial water resources in a dry continent such as Australia, 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

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, these bonds occur in a regulatory environment with no specific water quality guidelines for managing pit lake risks (Nguyen, 2006), yet in contradiction, mine waters have been internationally identified as the greatest off-site risk of mining to local communities and their environment (Younger, 2002). There are clearer standards for managing the vast masses of waste rock which may arise in the excavation of a open-cut pit and which may be the single largest cause of ecological impacts in a pit lake forming open-cut operation (Mudd, 2005). However, at present, there are only regulatory guidelines available for natural lakes, which may be overvalued, or otherwise inappropriate, compared to pit lakes *per se*. Furthermore, water use at many of Australia’s mines in their typically remote, arid locales, means that water use can represent a large proportion of the local supply (Brown, 2003).

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 for safety of the surrounding environment (Evans et al., 2005).

During active mining operations, pit water management is also 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). The result is lakes where biological processes are limited and chemical interactions dominate (Castendyk and Webster-Brown, 2006). Our experiences researching pit lakes in Australia suggest that even after 50 years that ecological processes are still very restricted (McCullough and Lund, 2006).

The liability that pit lakes represent to communities and the environment may be a legacy of the regional geography for many hundreds of years after leased relinquishment. Pit lakes present 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).

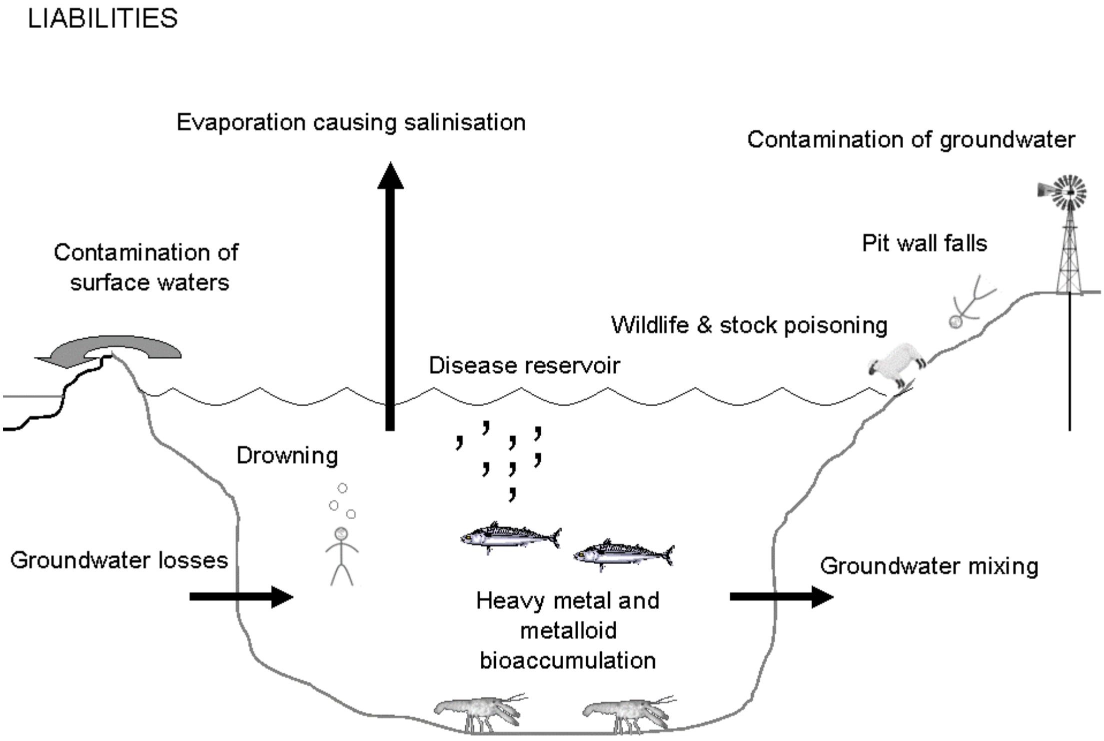

Figure 1. Potential liabilities of pit lakes to communities and the environment.

Wildlife drinking from pit lakes may ingest contaminated water which may 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 also be of concern to wildlife and communities utilising pit lake fisheries (e.g., marron, unpublished data).

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 such 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 the 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 more attractive to laying adult mosquitoes (Leisnham et al., 2006; Leisnham et al., 2005) and may form more significant sources of disease-carrying mosquito vectors in historical mining regions (Johnson and Wright, 2003).

Some region's pit lakes e.g., the western desert's Pilbara, Goldfields etc. may suffer problems associated with hyper-salinity. In areas with high evaporation rates and low groundwater flow rates, hyper-salinity may be caused by saline groundwater being drawn into these lakes through evaporation of pure water (Johnson and Wright, 2003). This tends to result in long term increases in salinity which is one of the most common types of pit lakes in hard rock mines (Commander et al., 1994). In addition to direct loss of habitat through reduced groundwater levels, deteriorated groundwater quality may seep into and contaminate either underground (stygofauna) biotic communities (Environmental Protection Authority, 2005), or overflow into surface water environments utilised by communities and biota (Kuipers, 2002; Younger, 2002). Nevertheless, groundwater quality deterioration by mining has been considered inconsequential in some areas which are deemed only useable for mining purposes (Taylor et al., 2004).

In higher rainfall areas such as Collie in Australia's south-west, 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 groundwater. Contaminants in the pit lake, such as heavy metals, may be transported into the groundwater and surface water systems downstream (Mudd, 2002b). Contamination of thru-flow groundwaters may have profound consequences for natural and human communities in arid regions of Australia where they are almost entirely dependent on groundwater (Mudd, 2002a).

Remediation by fast-filling through river-diversion may fill pit lakes in a timescale of only years (Schultze et al., 2002; Schultze et al., 2003). However, groundwater filled final pit lake levels, and chemical and biological conditions of both pit lake types may take centuries to reach equilibrium levels (Johnson and Wright, 2003).

Predictive geochemical modelling of pit lake water chemistry offers a powerful tool for both negotiating relinquishment or lease and pit lake and also for the preparation and ongoing management of final hydrology and water quality of these lakes (Castendyk and Webster-Brown, 2006). Modelling tools are of increasing attraction to both environmental regulatory authorities and mining companies alike. 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, pit lake chemical and ecological 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).

However, although the primary use of predictive water quality models is to satisfy regulatory agencies, water quality notwithstanding, is only one of the issues needing consideration for pit lake health and safety. Equally important may be remaining health and safety issues such as final pit lake water heights and interactions with surrounding water bodies, flood risks, disease-sources, etc.

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 they will continue to be left to from as mining companies cease their operations and leave.

Sustainable pit lakes

Probably the most commonly quoted definition of sustainability for society’s 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 is; minimising long term risks of pit lakes, whilst maximising benefits, for both short and long terms and for all stakeholders. Defined as goods or services provided by the mine lake that provide economic, health, welfare, safety or aesthetic benefits to the community, pit lakes may, however, represent an unconsidered source of many beneficial end uses frequently untapped in the pursuit of lease viability and profitability (Doupé and Lymbery, 2005; Johnson and Wright, 2003) (Figure 2) (Table 1).

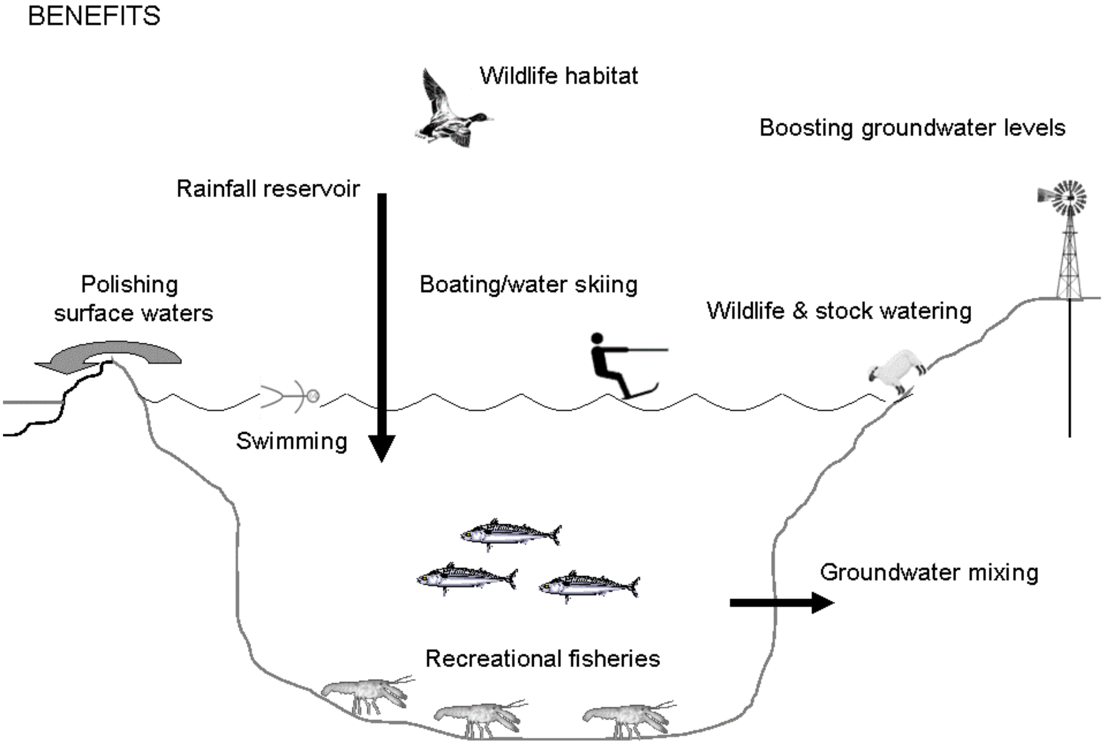

Figure 2. Potential benefits of pit lakes to communities and the environment.

Indeed, 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 local communities and, whilst unrecognised and unregulated by local authorities, already well-established in many arid mining regions with reasonable pit lake water quality (pers. obs.).

Other, more complex opportunities, will require specific direct support from mining companies, regulatory authorities; and in all situations the willingness and acceptance of local communities as well. However, in most of these cases the local community will also be a direct beneficiary of such opportunities, e.g., aquaculture and irrigation direct contributing to local business ventures, employment and income (Doupé and Lymbery, 2005).

Table 1: Examples of Australian pit lake end uses beneficial to mining companies, their local communities and their 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)
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, 5th February, 2004)
Recreation and tourism	Boating, water skiing, bathing	Historic and new Collie pit lakes (coal) (Chapman, 2002; Lund, 2001; 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, south-west Western Australia (coal) (Bills, 2006)

Furthermore, a widely accepted definition of health takes the potential benefits of a pit lake legacy even further than just that normally considered by regulation of impacts and creation of specific end uses. This definition states that "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.

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 the 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 (Examples 1–4). Although pit lake opportunities may be desirable, a fundamental constraint upon the type of opportunity able to be undertaken is also frequently that of the existing or future pit lake water quality (Doupé and Lymbery, 2005). Although much pit lake water remediation technology is new and only recently being applied to full-scale projects, the science of many remediation strategies is well-established with 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 increasing recognition that current and future pit lake benefits may be untapped (Klapper and Geller, 2002). “Passive” remediation systems are technologies where maintenance and energy input are minimal. Examples of passive treatment systems such as engineered wetlands may also have significant attraction due to their ability to be integrated into the surrounding landscape providing for community amenity, aesthetics and wildlife habitat (Younger, 2000).

Example 1. The Collinsville Coal Project (North Queensland)

The Collinsville Coal Project lease has seen 100 years of mining and now has many large 0–50 years old (500 ML) pit lakes containing “classic” acid mine drainage (AMD) waters with pH levels of 2.4, sulfate of 9 g L^{-1}, iron of 620 mg L^{-1} and aluminium of 140 mg L^{-1}. The Collinsville Coal Project lease lakes are sinks for groundwater, and increasing salinity is a potential problem.

A major use of water in this operation is for road dust suppression of the haul roads. However, to protect offsite natural surface watercourses, only the use of low salinity waters are permitted by regulatory authorities, making pit lake water unsuitable.

Treatment of these waters using sewage and greenwaste has been demonstrated by the authors in laboratory trials and is now being undertaken in a field pilot experiment (treating approximately 50 ML) (McCullough *et al.*, 2006). The treatment has increased pH, electrical conductivity has decreased markedly, and concentrations of sulfate, metals responsible for the high acidity and heavy metals also decreased. This approach stimulates naturally occurring sulfate reducing bacteria, to essentially reverse the process that initially generated the acidity. The treatment results have shown that even highly acidic pit lakes have potential to be inexpensively remediated with “low grade” organic materials such as municipal green waste and sewage. In fact, the warm climate of many of the large-scale mining operations in remote arid Australian areas facilitates passive remediation treatments.

Figure 3. Garrick East pit lake, Collinsville.

Example 2. The 45 year old coal pit lakes of Collie (Western Australia)

In the 1960's the collapse of Amalgamated Coal following a dispute with the State Government resulted in the immediate abandoning of five open cut pits (Stedman, 1988). Four of these have formed pit lakes (one was used for sanitary landfill), two are on public lands and two will eventually be re-mined. The pit lakes have changed little in over 45 years other than the loss from the water of most metals and acidity. Iron and aluminium concentrations across these various lakes range from only 2.5–50 µg/L and 6–2,050 µg/L respectively. Sulfate from 30–90 mg/L and pH from 3.5–5.0.

These pit lakes act as flow thru lakes or groundwater recharge (Varma, 2002). Low sulfate levels limit opportunities for using sulfate reduction to increase pH (see contrast with Example 1) (Lund et al., 2006). However our current research at laboratory and field trials indicates that combinations of liming, organic matter additions and the addition of nutrients are required in small quantities to remediate these water bodies potentially producing lakes with exceptional water quality suited to a range of beneficial enduses (Neil et al., 2006).

Figure 4. Black Diamond Lake, Collie.

Example 3. Lake Kepwari (Collie, Western Australia)

Mined between 1970 and 1996, the Wesfarmers Western 5B pit (100 ha in area, 70 m deep) was rapid filled with water from the Collie River. Extensive rehabilitation has been undertaken around the periphery to create a recreation resource (swimming & water skiing). The pit lake was renamed Lake Kepwari to reflect its new status. The inputs from the river ensure that this lake recharges the groundwater, however it is currently not known whether river inputs will be continued into the future.

Black Diamond, Collie

Despite rapid fill, pH in the lake is lower than desired at pH 5, (ANZECC/ARMCANZ, 2000) and ecotoxicological work indicates the water still remains unsuited to sustaining biodiversity (Neil et al., 2006). This limitation is probably due to ongoing elevated aluminium concentrations (*ca.*1,000 µg/L) and elevated heavy metals. Treatment with limestone and nutrient additions have improved pH and reduced the toxicity of the waters in a mesocosm experiment being conducted by the authors and their students.

Figure 5. Lake Kepwari, Collie

Example 4. Water supply in Laverton (Western Australia)

Laverton is a small town (population ~2,000) in the north-eastern Goldfields that supports nearby nickel and gold mining operations. Fresh groundwater in the region contains unacceptably high levels of nitrate for potable use and is therefore blended with water from Wedge Pit which has fresh water low in nitrates. Arsenic occurs in the neutral pH pit lake water but is easily treated by conventional means. This arrangement removes the necessity to use reverse osmosis treatment (as used in many other Goldfields' towns) which is very costly. It is believed that Wedge Pit water is fresh as it has large inputs of surface runoff when it rains which recharge the groundwater, as has been observed with other Goldfields' pit lakes (Connolly and Hodgkin, 2003). Exploitation of this resource has to be carefully managed to ensure that sufficient freshwater is maintained in the pit to prevent more brackish groundwater intrusion.

Figure 5. Wedge Pit Lake, Laverton.

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 semi-arid and arid interior.

It follows that a parochial pit lake management view that only considers minimisation of liability, may miss 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 and 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 also 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 are often oriented primarily towards mining operations as being 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. Indeed, communities benefiting from pit lakes are more likely to support lease relinquishment than those that are left with a null liability situation, or even worse a liability remaining from their local pit lakes. Water quality may initially, or eventually, restrict many 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 opportunities for benefits. As such, there is increasing emphasis on what potential ‘beneficial end-uses’ pit lakes may offer (Axler et al., 1998).

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

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