# PIT LAKES: BENEFIT OR BANE TO COMPANIES, COMMUNITIES AND THE ENVIRONMENT?

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## ABSTRACT

Due to operational and regulatory practicalities, pit lakes will continue to be common legacies of 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. Frequently unrecognised is the potential for pit lakes to provide benefit to companies, communities and the environment. Sustainable pit lake management aims to better minimise short and long term pit lake liabilities, and maximise short and long term pit lake opportunities as well. Improved remediation technologies are offering more avenues for pit lakes resource exploitation than ever before, at the same time that mining companies, local communities and regulatory authorities are also more aware than ever of the benefit of these water resources.

## BACKGROUND

A potential legacy of open-cut mining is the pit 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 & Moore, 1997). Although backfill may be considered a simple solution to the formation of pit lakes, it is often not cost effective or even desirable. For example, historically new pits are often of too large a scale to be readily backfilled, or backfill geologies may risk contamination of groundwaters. These remaining 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).

There are an estimated 1,300 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 & Wright, 2003). As pit lakes these have no natural counterparts in the Western Australian landscape where natural lakes tend to be shallow and seasonal. Therefore these pit lakes represent a novel addition to the aquatic resources of the State. 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). Pit lakes have been divided into three basic hydro-geochemical environments in Western Australia by Commander *et al.* (1994).

**_Groundwater sinks_** in areas with high evaporation rates and low groundwater flow rates. Groundwater is drawn into these lakes through evaporation and doesn't exit. This tends to result in long term increases in salinity. One of the most common types of pit lakes in hard rock mines (Examples 1 & 2).

**_Flow thru pit lakes_** groundwater flows through the pit lakes due to high flow rates of groundwater. Groundwater downstream of the pit lake tends to be more saline than groundwater inflow due to evapo-concentration in the lake.

**_Groundwater Recharge_** inflow into the lake exceeds evaporation resulting in a flow of water out of the lake into the groundwater. Although this generally avoids salinity problems, contaminants in the lake can be transported into the groundwater (Examples 3 & 4).

Pit lakes tend to have a low surface area to depth ratio compared to natural lakes and have steep sides. On filling they generally do not contain the range of organic materials that typically are found in natural lakes. The steep sides are usually unable to develop a natural sediment covering. Unless the edges of the pit lake have been sculptured, they are often unsuited to the growth of emergent plants (rushes). The result is lakes where biological processes are limited and chemical interactions dominate. Our experience in Collie and Collinsville (see Examples 1 and 2) suggest that even after 50 years that biological processes are still very limited. In addition, to physical and hydrogeological differences to natural lakes, some pit lakes suffer problems associated with hyper-salinity or contamination with metals, typically from acid mine drainage (see Example 1) (Harries, 1997), but also from other sources (see Example 4) (Banks *et al.*, 1997).

### To pit lake or not to pit lake

Although generally preferred by regulators, complete backfills of pits with waste rock, tailings and/or operation wastes are rare due to the high expense involved and potential contamination issues associated with the fill. Accordingly, partial backfills may be desirable to reduce the size of final pits. Partial backfills may also resolve groundwater interaction issues, and can be used to keep pyritic materials in lower oxidation environments.

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.

## PIT LAKE MANAGEMENT

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 & Ashton, 2000; Evans *et al.*, 2003).

Pit lakes present significant health and safety issues for both the mining company and adjacent communities (Doupé & Lymbery, 2005). For example, pit walls can be unstable, and can become more so during lake filling. Pit lakes may also harbour waterborne diseases and their vectors such as mosquitoes (Pilbara Iron Ore Environmental Committee, 1999). The proposed pit lake must also be managed so that local communities and the environment are also not placed at risk from flooding and overflow of a contaminated pit lake water into natural surface and ground waters (Kuipers, 2002; Younger, 2002). The potential for deterioration of pit lake water quality may also require initial and/or ongoing management of salinisation, acidification, and elevated metals.

In short, to be successful, any lease relinquishment strategy which proposes final pit lake formation, must have well-considered pre-filling and post filling strategies.

## Modelling the future lakes

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. 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 & 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 these lakes (Castendyk & Webster- Brown, 2006). Modelling tools are of increasing attraction to both environmental regulatory authorities and mining companies alike.

However, although the primary use of predictive water quality models is to satisfy regulatory agencies, as discussed water quality 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-source, etc.

Furthermore, 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 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 (Figure 1) (Wright, 2000). In areas with a history of underground mining prior to open-cut mining, these differences may be even more profound. For instance, pit lakes typically have very different and more complex interactions with their groundwaters than do most natural and constructed water bodies of similar scale. Pit lakes also frequently have more geochemically complex and poorly mapped catchments.

**Figure 1: Abiotic influences upon pit lake water chemistry (after Johnson & Wright, 2003).**

Fundamental to the slower processes which are still significant to long-term water quality, models generally ignore complex, intrinsically variable and poorly-understood biological processes within the lakes. The ecological development of the pit lake may have profound influence on water chemistry over the long term, especially at circum-neutral pH values (Davison *et al.*, 1995).

## Pit lake standards

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). These bonds occur in a regulatory environment with no specific water quality guidelines for pit lakes. At present, there are only guidelines available for natural systems, which may be overvalued, or otherwise inappropriate, compared to pit lakes. Consequently in Western Australia, regulation of pit lake water quality 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).

## Sustainable pit lakes

The minerals and energy industry in Western Australia is a high value user of water largely self-supplied from groundwater sources across the State. Much of this water is hyper-saline, and as such, is often considered of little other beneficial use (Western Australia Chamber of Minerals and Energy, 2004). Nevertheless, being a finite abstraction, mining is an inherently unsustainable industry for the locally affected area. As a result, sustainability of mining leases with significant pit lakes is as much about minimising the long term risks of pit lakes whilst also maximising their benefits over both short and long terms and for all stakeholders concerned. Consequently, pit lakes need to be planned for (Evans & 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).

## PIT LAKE OPPORTUNITIES

In contrast to the risks and liability which pit lakes may represent to companies, and adjacent communities and environment, pit lakes may also represent significant benefits, frequently untapped in the pursuit of lease viability and profitability. Some of these pit lake opportunities such as recreation are already well-established in some arid mining region with reasonable pit lake water quality (Table 1). Other opportunities will require specific direct support from mining companies, regulatory authorities; and also in many situations the 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 directly contributing to local business ventures, employment and income (Doupé & Lymbery, 2005).

**Table 1: Examples of pit lake opportunities to mining companies and their local communities and natural environment.**

| Opportunity | Example |
|---|---|
| Recreation and tourism | Historic and new Collie pit lakes (coal) |
| Wildlife conservation | Capel Lakes, south-west Western Australia (mineral sands) |
| Aquaculture | Granny Smith Mine, Goldfields (gold) Wesfarmers, south-west Western Australia (coal) |
| Irrigation | Enterprise Pit, Northern Territory (gold) |
| Potable water source | Wedge pit, Goldfields (gold) |
| Sacrificial | Chicken Creek, south-west Western Australia (coal) |
| Industry water | Collinsville Coal Project, North Queensland (coal) |
| Research and education | All pit lakes |

### 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 upon the type of opportunity able to be undertaken is also frequently that of the existing or future pit lake water quality (Doupé & Lymbery, 2005). Nonetheless, remediation is increasingly available for some of these 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 & Geller, 2002). 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. Following are some examples of uses that are able to be made following remediation of pit lake water.

**Example 1.** *The Collinsville Coal Project (North Queensland)*

This 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 $L^{-1}$. These 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 Australian areas facilitates passive remediation treatments.

**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 5 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. pH ranges from 3.5 to 5.

These pit lakes act as flow thru lakes or groundwater recharge (Varma, 2002). Low sulphate levels limit opportunities for using sulphate 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.

**Example 3.** *Lake Kepwari (Collie, Western Australia)*

Mined between 1970 and 1996, the Wesfarmers Western 5B pit (100 ha in area, 70m 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. This is currently one of the foci of intensive modelling efforts at CSML.

Despite rapid fill, pH in the lake is lower than desired at pH 5.0, (ANZECC/ARMCANZ, 2000) and ecotoxicological work indicates the water still remains unsuited to sustaining biodiversity (Neil *et al.*, in prep). 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.


**Example 4.** *Water supply in Laverton (Western Australia)*

Laverton is a small town (Population ~2000) 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 & 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. Shan Sureshan (Water Corporation) will be evaluating this resource as part of a Ph.D. at Edith Cowan University supervised by the authors.

## CONCLUSIONS

Pit lakes will continue to contribute to the legacy of the mining industry across the globe. However, there remain significant knowledge gaps which restrict our confidence in determining the potential liability of pit lakes and in what opportunities pit lakes can best provide benefits (Wolkersdorfer, 2004). One of these fundamental questions is how biological communities develop in pit lakes and how this developing ecology may alter water quality in the short and long term. There is also great variety in pit lake water quality over often surprisingly short distances. For example, why are some pit lakes freshwater, and how sustainable are these then as resources? Knowledge of pit lake's chemistry and development is also often inadequate for much of Australia's differing climatic and geological regions. As a result, pit lake currency and prediction of some of these regions are particularly poorly understood e.g., the Goldfields region

Nevertheless, a 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. These opportunities and benefits extend beyond the mining company to the local community and also the environment. Although mining companies and their local communities will be clearly 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 neutral situation or even worse a liability remaining from their local pit lakes. Although water quality may initially, or eventually, restrict these opportunities, current and emerging technologies may enable remediation of these mine waters to standards whereupon they can then be used for these beneficial purposes.

In conclusion, for best sustainable management of lease resources for companies, communities and the environment, pit lake management can be more than simply meeting 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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