Regulator guidance and legislation relevant to pit lakes

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Abstract

Open cut mining that develops pit lakes is common internationally, but regulatory guidance specific for pit lake formation and development is sparse in the international context. Instead, approaches toward pit lake development have generally been made by considering every mine site as unique. As a result, current international practice is that development of pit lakes should, and are generally managed on a case-by-case basis. There are a wide range of broad but non-specific forms of regulatory direction and processes such as water quality guidelines to allow for an initial decision-making strategy on whether it is desirable for pit lakes to form and as to what potential end uses may be. However, most of the regulatory guidance focusses heavily on risk as the sole pit lake end point at mine closure. Development of clear social or environmental end use goals in pit lakes uses may provide either provide benefit or to even offset some of the risk.

Once an end use goal is established and comfortably articulated as fitting with broader company sustainability strategies, it will assist in the development of general conceptual plans for a mine pit lake at lease relinquishment. It will also serve to inform regulators of a well-developed concept for going beyond current broad guidelines for pit lake formation and management to better achieve corporate goals of sustainability and social licence-to-mine.

The timescale for the evolution of lakes as end uses may be in the order of hundreds of years. In order to be successful, presenting a well-developed pit void closure plan to regulators and stakeholders should ideally be the conclusion of many years of a well-developed strategy of testing, refinement and stakeholder engagement of an end use development proposal.

1 Introduction

Open cut operations by mining companies operate internationally in countries with varying governmental regulations and guidance for mine closure. The purpose of this chapter is to assess the current state of regulations, guidelines and current operating practices that address the closure expectations and practical realities of mine pit lakes remaining at the completion of open pit mining. We contacted a wide range of people working in the field of managing pit lakes both within Australia and internationally. These people were consultants, regulators, operators working on existing mines and researchers working in the field.

1.1 Regulation forms

There are real legal differences between Guidelines, Codes of Practice, ministerial conditions and regulation in countries that have a common (British) law basis for their legislation (Jones, 2008). These can be roughly outlined as shown in Table 1. Historically new technical issues in the mining industry are initially addressed by guidelines which may then be superseded by regulations if the industry's response is considered ineffective. Guidelines are also often used by governments as *de facto* regulations. In Australia, ministerial conditions issued as part of the approval process for establishing a mine are becoming more detailed in their closure requirements over time reflecting an increased concern by government regarding mine closure.

Table 1 Forms of pit lake closure "regulation"

Regulation	Detail
Guidelines	Intended as guidance. Following the advice in a guideline is not compulsory nor is it normally a legal requirement as guidelines should not normally be incorporated into legislation.
Codes of practice	Give advice and/or directions on how to comply with the law. Generally speaking, failure to follow an approved Code of Practice is considered a breach of the relevant regulation.
Regulations	Approved by government and part of the law of the land. Can be general or detailed and explicitly state what needs to be done and lists penalties for non-compliance.
Ministerial conditions	Usually site specific and are attached to a specific mining tenement or licence. Failure to meet the conditions can result in the loss of that tenement or licence.

An important point is that all of the above are liable to change. This is important for three reasons:

1. Both guidelines and legislation can result in unintended consequences.
2. Simply meeting today's standards may not be sufficient to meet future community requirements and expectations.
3. Technology changes for the mining industry.

Legislation can either be directed at processes (prescriptive) or towards outcomes (enabling). Prescriptive legislation may dictate how the pit lake can be built, while enabling legislation defines the outcome the pit lake must attain, without constraining the means by which those criteria can be met.

Generally speaking, prescriptive legislation is a poor method of addressing the long-term environmental requirements of waste landforms because it is imposed across all mine sites, irrespective of site specific conditions and discourages the development of an optimal solution for any particular mine. An example of this is if water quality guidelines for environmental protection are specifically applied to protection of pit lake water ecosystems.

Enabling legislation is more likely to result in acceptable post-mining landforms by setting outcomes for the new landforms, including the pit void lake, without constraining the designers. This approach requires the mining company to consider the site specific conditions and arrive at a design much closer to the optimum for that site than the application of a set, one-size-fits-all design.

It is common for more than one regulatory authority to have responsibility for the environmental aspects of mine closure and in many cases a formal Memorandum of Understanding has been drawn up by the responsible authorities to define their respective regulatory processes and responsibilities. Counter to most terrestrial restoration requirement and approaches, there appears to be no consideration to development of multiple pit lakes as landscapes, e.g. as lake districts outside of these individual pit void lake assessments (McCullough and Van Etten, 2011). The general approach of all jurisdictions to this issue is very similar, namely to assess each open pit void and its lake in isolation on a case-by-case basis as part of the general closure requirements. For example, in Western Australia the Environmental Protection Authority (EPA) has used the process of Conditional Ministerial Approval under the *Environmental Protection Act* to recommend to the Minister closure conditions for individual mines.

Some ministerial conditions that relate to water in open pit voids are prescriptive, such as Condition 7.1 for the Windarlind W2 pit (Ministerial Statement No. 802, published on 18 August 2009).

> *"Subject to conditions 7-4 and 7-5, the proponent shall ensure that grazing and predation do not cause an increased impact on flora and fauna in the vicinity of the mine, by backfilling the Windarlind W2 Pit void to a level that will prevent the formation of permanent surface water on cessation of pit dewatering."*

Other ministerial conditions are more enabling, such as Condition 11-2 for the Southdown Magnetite Proposal (Ministerial Statement No. 816, published on 25 November 2009).

> *"The proponent shall ensure that after mine closure the final pit void:*
> 1. *does not cause significant groundwater contamination; and,*
> 2. *does not cause material or significant environmental harm to native fauna."*

It should be noted that the Windarlind W2 pit ministerial conditions (conditions 7-4 and 7-5) do provide for alternative solutions, should backfilling be found non-viable. However, it was unspecified and likely undetermined as to which specific animal species are considered at risk from these pit lake developments, if any. Equally there is typically no consideration of pit lakes providing any benefit to local wildlife.

2 Hydrogeology

2.1 Australia

The Western Australian Government has published a detailed water-related resources and guidelines for mining in Western Australia that are of close relevance to pit lake creation. "Mine Void Water Issues" (Johnson and Wright, 2003) presents a then current overview of pit lakes in Western Australia and discusses the management of water remaining in pit voids after mine closure.

The Western Australian government's Department of Mines and Petroleum (DMP) and the Office of the Environmental Protection Authority (EPA) have recently jointly prepared *Draft Guidelines for Preparing Mine Closure Plans* (DMP/EPA, 2011). These guidelines are unusual in that they explicitly provide guidance on pit lake issues. Pit lakes with poor water quality are recommended to be isolated from the environment (including fencing and bunding as required), pit lakes with saline water/developing salinisation are addressed as potential contamination and ongoing abstraction of regional water resources or for watering feral goats (Dunson, 1974; Burke, 1990). Pit lakes with good water quality are also addressed as potential risks for feral predators, grazers and stock animal watering which could impact upon nearby vegetation and disease vector, e.g. mosquito habitat reservoirs.

Figure 1 Over-grazing of rehabilitation vegetation around a pit lake in Western Australia by feral goats (Photo courtesy of H. Jones)

These two guidelines demonstrate a strong and internationally universal theme by Government to protect the beneficial use of existing water resources; be they ground or surface waters. In Australia, this appears to be the main driver for increasing prescription that mining operations in some regions backfill the final void to a level above the potential ground water recovery when mining ceases. Although such guidance highlights backfill as the most risk-free alternative to pit lakes, typically little guidance is available for partial backfill scenarios, or certain waste types (e.g. AMD materials), for maintenance of certain hydrogeological conditions, for specific wildlife habitat types or approaches to be used in different climatic zones.

2.2 North America

Canada and USA have a considerable interest in abandoned mines; particularly mines that have discharges of low pH water that potentially contain chemistries considered toxic such as elevated concentrations of cadmium, selenium and mercury. In all of these cases the focus is on discharges from the mines into the surrounding environment and little concern was expressed regarding situations where the water in the mine remained in the mine area.

The USA and Canada have a similar approach to mine reclamation in that the legislation is found in multiple legislative acts that govern mining (making it sometimes a complicated regulatory framework) (Garcia, 2008). Legal requirements for mines proposing to form pit lakes in the US are linked to a number of federal laws governing mining activities and any activity that could harm the environment. A significant difference, however, is that the US has further specific legislation for coal mining activities that would influence those specific pit lake types (Williams, 2009).

When pit lakes are proposed by in mining plans, both state and federal regulatory agencies in the US generally require detailed geochemical modelling of projected water quality as well as hydrological and hydrogeological modelling of water quantity and pit filling rates and final water heights (Vandenberg, 2011). Sometimes these are required as part of their mining proposals (often by federal mining licence permitting regulators), sometimes they are required as part of closure plans (often at state level). This modelling may extend for decades or longer into the future to assure long-term water quality; the longer it extends the less reliable the model will become due to internal (e.g. inaccuracies in model parameter determination such as groundwater transport rates) and external factors (e.g. change in pre-empted environmental conditions such as through climate change) (Miller et al., 1996). Regulatory agencies also typically require monitoring of both water quality and quantity as pit lakes fill to validate modelling projections. In the event that water quality of a pit lake does not meet relevant water quality standards, it may be necessary to implement a water treatment programme to assure that surface and groundwater are protected. Implementation of required water treatment programmes will generally require detailed design studies, construction of treatment facilities, and planning for potentially perpetual operation and disposal of associated waste products. The requirement for ongoing operation of water treatment systems following mine closure and lease relinquishment is the reason for interest in passive (sometimes erroneously called walk-away solutions) (Neculita et al., 2007) to mine water quality using a variety of ecotechnological approaches (Wren et al., 2011; Kumar et al., 2011).

State laws in the US are unclear as to whether pit lakes as final mining landforms are acceptable or not. Instead, state laws generally rely on other relevant laws regarding ground and surface water quality, and their proposed end use by wildlife and/or humans to determine whether a pit lake would be acceptable or not. Provincial and state regulations and often company expectations are often to returning mining landscapes to some level of productive use, hazard reduction and stable landforms (Tuttle and Sisson, 1998; Government of Alberta, 2009; Williams, 2009; DMP/EPA, 2011). Consequently, it is unlikely that a pit lake with predicted poor water quality would be permitted in the US without an approved plan for remediation at closure, e.g. perpetual external or in situ water treatment, water diversion, backfilling, etc.

One example of a large open pit lake being managed by both federal and state authorities in the USA is the Berkeley Pit in Butte, Montana (Frank, 2000). This has been the centre of extensive underground and open pit mining operations since the 1870s (Gammons, 2011) with open pit mining beginning in 1955. Operations were suspended in 1982 and after the pumps were shut down, groundwater levels started to rise immediately to about 396 m by the end of 1982 and to 914 m by the end of 2000. The chemistry of the bulk of the water included a pH of 2.5, specific conductance of 8,600 $\mu S\ cm^{-1}$ with dissolved copper and zinc concentrations of 190 and 620 mg/L respectively.

A maximum level to which water will be allowed to reach has been set by the US Environmental Protection Agency and the Montana Department of Environmental Quality. The aim is to maintain the Berkeley Pit as a "Terminal Pit" thereby ensuring that the water in the pit is hydraulically contained (hydraulic sink, Commander et al., 1994). Such hydraulic control mechanisms can also make use of pit lakes in other regions of net evaporation as sacrificial pit lakes that protect the broader environment around the pit lake from surface and groundwater transport of toxicants from the pit lake (McCullough and Lund, 2006). However, prescriptive regulation may form an obstacle to this type of closure design due to explicit failure to meet pit lake closure water requirements. If operating as designed, lake will evapo-concentrate acidity and metals to while providing local hydraulic drawdown. This means the lake will eventually fail to meet some water quality criteria, e.g. for environmental protection.

Pit lakes most often become a relinquishment issue if surface or groundwater quality is threatened or if the quality of the pit lake itself poses an environmental risk (Younger, 2002; Doupé and Lymbery, 2005). Nevertheless, there are no US laws that specifically prohibit pit lakes as a possible relinquishment option at closure; with the proviso that relevant ground and surface water quality regulations are still met.

Although regulation in the US is similar to Canada, different mineral ownership laws and a greater percentage of federal lands managed within individual states makes the regulatory environment of many mining situations potentially different to both Canada and Australia which have both federal and provincial/state Government systems, a well developed mining industry and a high standard of living and similar mineral ownership laws.

The Canadian Federal Government published the Environmental Code of Practice for Metal Mines (Environment Canada, 2009) which outlined the broad requirements for mine operation and closure. However, this publication did not specifically address the question of water potentially remaining in open pit voids at closure. Under the Canadian constitution, mining is a provincial responsibility. The federal Government has responsibility for the three territories, but is slowly devolving this to the territories. Several of the provincial guidelines, other regulations and published policies have more detailed reference to open pits, but again there is little detail on pit lakes specifically.

In direct contact provincial regulators all expressed a preference for dealing with all mine closure details on a case by case basis; albeit subject to broad water quality and public safety standards being maintained. For example, Saskatchewan's *Guidelines for Northern Mine Decommissioning and Reclamation* (Saskatchewan Ministry of the Environment, 2008), required pits lakes at mine closure to have water quality similar to what is found in local waterbodies. Water quality in deeper zones within flooded pits could be of poorer quality if these zones become isolated through the formation of a chemocline. However, stability of chemoclines had to be established (presumably through modelling (Boehrer and Schultze, 2006)) before closure.

The Alberta Government established an End Pit Lake Working Group which published *Guidelines for Lake Development at Coal Mine Operations in Mountain Foothills of the Northern East Slopes* (End-Pit Lake Working Group, 2004). While this document addressed the question of open pit voids after closure it was restricted in its application to surface coal mine operations in the Northern East Slopes Region of Alberta. It recommends broad physical, hydrological, chemical and biological criteria for end pit lakes, but cautions that site-specific conditions must also be taken into account. The End Pit Lake Working Group also stated that these guidelines stressed the importance of the continued use of adaptive management principles in the establishment of end pit lakes.

Given the Canadian climate, which almost always results in an excess of precipitation over evaporation, the concerns of the Canadian authorities are on the potential for contaminated water to escape from the mine site and affect local water quality. In most parts of Canada, pit lakes are not a choice, they are inevitable. Backfilling of end pit lakes can be considered in the case of strip mines (i.e. surface coal mines and oil sands), but it is not financially viable in many typical deep, hard rock mining pits. In the case of some of the end pits left after coal mining, they are to ensure that the quality of water remaining in the pit does not adversely affect local aquatic biota, in particular fish caught by the local community.

The public safety aspect of flooded open pits is addressed in Ontario by a specific regulation which requires that at least one sloped entrance shall be left or created to allow a reasonable exit point should inadvertent access occur (Ontario Government, 2007).

More recently, the Canadian oil sands industry's Cumulative Environmental Management Association (CEMA) has developed an end-pit lake committee with representatives from most major oil sand resource companies. CEMA's mandate is to produce guidelines and management strategies that will enable operators to achieve acceptable water quality for end pit lakes in the Athabasca oil sands region (Charette, 2011). The industry's first pit lake (of up to 26) is expected to be developed as a full-scale lake in 2012 and is expected to take 10 years to develop as an ecosystem.

Following initial lake development, intensive monitoring and adaptive design methods are recognised as being particularly important to make the right changes to design and management plans for these future pit lakes.

2.3 Europe

The European community (EU) undertook a research and development project with a consortium of partners from February 2001 to January 2004. The overall goal of the *Environmental Regulation of Mine Waters in the European Union* (ERMITE) project was to provide integrated policy guidelines for developing European legislation and practice in relation to water management in the mining sector (Amezaga and Younger, 2004). The extensive report produced did not specifically address the issue of water in mine voids except where those voids have resulted in water being released from the void and impacting on water resources in the surrounding environment. The considerable majority of the information collected focusses on old abandoned mine workings, mainly underground operations and on operations where there is a high level of pollution already existing.

The overriding concern for ERMITE is to prevent pollution resulting from mining and the concept of pit lakes is not specifically addressed. Significantly different to both Australian and North American approaches, however, there has been collective consideration for development of multiple pit void lakes across a region as a 'lake district'. For example, in the former East German lignite mining region of Lusatia, lakes are considered not only from their independent individual contribution to human and wildlife utility, but also on their collective contribution to landscape aesthetics and sustainability opportunities as a novel landscape that can be engineered to meet the needs and desires of local communities regulatory authorities and also regulators (Nixdorf et al., 2005).

Figure 2 Large pit lakes, as will flood this large open cut pit in Czech Republic (a), and multiple pit lakes, such as this one in Highland Valley, British Columbia, Canada (b), can alter the environmental and social dynamics of a region to that of a novel, but socially and ecologically valid pit "lake district" (Photo courtesy of C.D. McCullough)

2.4 South Africa

South Africa has a well developed series of guidelines published by the Department of Water Affairs and Forestry (DWAF, 2008).

Of these guidelines three have specific application to closure of open pits, namely G4, *Impact Prediction* and G5, *Water Management Aspects for Mine Closure*. These are best practice guidelines dealing with general water management strategies, techniques and tools, which could be applied across multiple sections. They are also explicitly considered under A5, *Water Management for Surface Mines*. The guidelines have been developed as part of the implementation of an integrated water resource management concept brought into being under the National Water Act 1998. The emphasis is on using risk assessments on a case-by-case basis to address the management of water in all phases of mining so as to minimise water pollution, preserve water resources and maximise the reuse of water that has been affected by mining. The guidelines appear to have been drafted to specifically complement each other and not as ad hoc responses to specific issues. There is strong recognition that each mine is unique and will therefore require a site specific closure plan.

The guidelines enable mining companies to comply with South African law by indemnifying them from any post-closure responsibilities. Instead, liabilities are directed to appointed third parties to be responsible for implementing any post-closure monitoring and maintenance programmes. This post-closure phase is required to continue until the residual impact of the mine has reached acceptable levels and no further ongoing maintenance work is required. Nevertheless, apart from these broad closure considerations, the South African guidelines do not specifically address the case of pit lakes, except where that water has the potential to contaminate the surrounding environment or a potential to be reused.

3 Pit lakes as post-mining landforms

3.1 Australia

Similar requirements exist in all states in Australia to provide mechanisms to prevent public access to mines that have been closed. The specific detail of the requirement varies from state to state, with some states allowing fencing around the open pit and others requiring a substantial bund.

Public safety of abandoned open pits in Western Australia is addressed by the Mines Safety and Inspection Act (1994) and the Mines Safety and Inspection Regulations (1995). In part the resulting regulations reflect a case of a member of the public successfully suing the WA local and state Governments for approximately A$1.8 million in damages following an injury at an abandoned open pit lake (Jones, 1996). The Western Australian Mines Safety and Inspection Regulations (1995) contain regulations that apply to the geotechnical considerations that must be adequately considered during the abandonment of an open pit excavation. The Department of Industry and Resources (DOIR) (now Department of Minerals and Petroleum (DMP)) publication *Safety Bund Walls Around Abandoned Open Pit Mines* (1997) requires that before open pits can be legally abandoned, that all long-term drainage, stability, and public access issues are adequately considered and controlled. Environmental requirements for abandoned mines are also specified by the license conditions imposed by the Department of Environment and Conservation (DEC) during the mining project approval process. The DOIR guideline recognises that all excavated pit walls have potential for failure and requires mine slopes to be designed to a standard which evaluates the consequence of failure and the inherent uncertainty in the geotechnical model used as the basis for the pit wall design.

3.2 North America

Public safety around open pits is commonly addressed by fencing and/or bunding of pit edges and a geotechnical assessment of the pit wall stability. In some provinces and states the regulations specify the type and location of fences and/or bunds, but in most cases this is not done. All Canadian provinces rely on the recommendations of the professional geotechnical assessment for achieving safety in the stability of the open pit walls at closure.

Quebec's *Guidelines for Preparing a Mining Site Rehabilitation Plan and General Mining Site Rehabilitation Requirements* nominate factor of safety numbers for waste rock dumps and tailings storage facilities at closure but do not nominate any such requirements for open pits. However, the guideline's appendix on stability criteria contains several statements which could also be applied to open pit walls. In particular, a requirement that stability calculations be based on all long-term conditions affecting structures. They are also required to take anticipated static and dynamic loads and gradual alterations in construction material properties into consideration.

3.3 Europe

Many of the nations in Europe have a requirement to prevent public access by fencing off all open pits at closure, but the responsibility for constructing and maintaining the fences is often not clear, as many of the mine sites are the responsibility of local Government authorities, rather than the national Government. Due to population pressures in historical mining regions, many abandoned open pits in Europe have now become recreation areas (Pearman, 2009); either organically or with oversight and design. With the development of lakes for boating, water bird sanctuaries and fun parks the public is increasingly encouraged to visit these abandoned mine sites at an intensity not seen in other historical mining sites with pit lakes.

4 Acid and metalliferous drainage

Mine metal drainage is known variously as acid mine drainage (AMD), acid rock drainage (ARD), mine metalliferous drainage (MMD) and acidic and metalliferous drainage (AMD). AMD was documented as long ago as Roman times. The process normally requires three basic drivers, sulfide minerals that are able to oxidise in the prevailing conditions at the mine, oxygen and water to enable the acid forming reactions to be initiated and water also so that the acid can be transported from its place of formation. Some common observations of AMD (Costa and Duarte, 2005) provide pointers to the nature of the oxidative process:

- AMD may be delayed in development – onset may occur some significant time after mining operations begin, and AMD is commonly a greater problem after mining ceases than during the life of the mine.
- Once AMD is initiated, acid production may increase exponentially – there is a tendency for the quantity and/or concentration of AMD to escalate and appear to become out of control.
- Once AMD is established, a return to former anoxic conditions may not halt its progress.

However, the AMD-generation process can be mitigated by:

- Minimising the excavation of rocks containing the sulfide minerals.
- Minimising contact between sulfidic minerals and water and oxygen.
- Minimising transportation by water.
- Neutralising any acidic discharges.

4.1 Regulations

AMD is often a significant concern for the international mining community, particularly the threat elevated concentrations of metals/metalloids can pose to ecosystems living downstream from AMD pollution sources (McCullough, 2008).

4.2 International

The Global Acid Rock Drainage Guide (GARD Guide) from the International Network for Acid Prevention (INAP) consolidated relevant information and summarised technical and management practices for industry and stakeholder use. This guide provides a structured system to indentify proven techniques for characterisation, prediction, monitoring, treatment, prevention and management of ARD (Verburg et al., 2009).

4.2.1 Australia

The Australian Commonwealth and State Governments do not have specific regulations to AMD. However, the Commonwealth has published a series of guidelines in its *Leading Practice Sustainable Development Programme for the Mining Industry including Managing Acid and Metalliferous Drainage* (September 2007) which is regarded by Australian regulators as best practice and is sometimes quoted as de facto regulation.

The Western Australian DMP and EPA has also recently released draft *Mine Closure Guidelines* (DMP/EPA, 2011) which explicitly consider AMD as both acidic and neutral/alkaline discharge environmental hazards, recommending 6 or even 12 month kinetic leach tests to fully ascertain risk.

4.2.2 North America

The most detailed information and guidelines relating to the development of acid in mine waste materials, sampling and testing procedures and the mitigation of potential mine metal drainage is contained in the Mine Environment Neutral Drainage (MEND) programme, a joint initiative of governments and industry.

This series of guidelines are increasingly being accepted by regulators as the most reliable source of information concerning sampling and analysis, prediction, prevention, control, treatment and monitoring of acid generated as a result of mining.

4.2.3 Europe

The European Parliament in 2006 issued a Directive (2006/21/EC) on the management of waste from extractive industries and in 2009 supported aspects of this Directive with a commission decision "*completing the technical requirements for waste characterisation laid down by Directive 2006/21/EC of the European Parliament and of the Council on the management of waste from extractive industries*". This decision is now in the process of being incorporated into law by the Members of the European Community.

The commission decision on waste characterisation is a high level document that sets out broad requirements for characterising waste resulting from extractive industries (which includes mining). Its key requirement is that waste characterisation addresses five aspects, namely background information, geological background of deposit to be exploited, nature of the waste and its intended handling, geotechnical behaviour of the waste, and the geochemical characteristics and behaviour of the waste.

Environmental Regulation of Mine Waters in the European Union (EU) (ERMITE) (Amezaga and Younger, 2004) provides integrated policy guidelines for developing European legislation and practice in relation to water management in the mining sector, which was funded by the European Commission 5th Framework Programme. ERMITE addresses the various regional and national conditions in EU Member States and some Eastern Europe countries involved in the enlargement process by integrating different disciplines: water resources, mining, ecology, economy, law, institutions and policy.

4.2.4 Government surety

Performance bonds as government surety can be expressed as letters as credit or similar financial arrangements, or even cash commitments. They are intended to guarantee to government finances to cover the cost of mine closure should the operating company be unable to meet its closure obligations, are becoming common in many mining jurisdictions. These surety arrangements are normally established prior to mine permit approval and held on behalf of a government pending appropriate rehabilitation and final relinquishment of mining leases.

Bonds are still typically insufficient relative to accepted standards of rehabilitation and cannot be considered as an incentive for pit lake development to meet standards where social and environmental end uses may be met. Performance bonds therefore internationally present little direct incentive to a company's relinquishment performance. Furthermore, when performance bonds occur in regulatory environments with few specific guidelines for relinquishment of mine leases with pit lakes as they often do internationally, bonds provide little incentive to develop pit lakes for relinquishment outside of the generic legislation already described. Even if bonds are taken, these bonds may be released prior to achievement of satisfactory pit lake relinquishment standards. For example, when a regulatory agency believes that in the event of rehabilitation performance failure, the country/state can legally recoup enough monies to rehabilitate the site appropriately through other means.

5 Social aspects

Mine closure regulations for many jurisdictions do not specify legislative requirements for stakeholder consultation during mine closure. However, there has been increasing pressure from regulators and the public for the mining industry to engage with stakeholders in a documented process throughout the life of a mine as a social licence to mine (Nelson and Scoble, 2005). The goal of closure is typically to minimise future environmental impacts and to reduce future financial risk to the company's shareholders. Financial institutions such as the International Finance Corporation (IFC) have emphasised the importance of closure for socially conscious and fiscally safe banking purposes and there are broad programmes that financial institutions can adopt to manage the environmental and social risk of mine closure (Garcia, 2008).

It is generally assumed that pit lakes will follow an evolution from newly filled pit lakes with more environmental and social risks to mature lakes with better water quality and a well-developed ecosystem (Kalin and Geller, 1998). Although long-term issues may not be considerations in shorter timeframes that many regulatory authorities and pit lake closure regulations may be primarily interested in, these longer time frames still represent a significant issue for mine closure in a broader sense through the long-term sustainability of regional communities and environments. Consequently, without confident predictability, regulators may consider pit lakes to significant health and safety risks for regional human and wildlife communities, for many hundreds of years following cessation of mining operations (Doupé and Lymbery, 2005). As such, the environmental and social liability that pit lakes represent to communities and the environment is often considered a significant legacy of the regional geography after lease relinquishment (McCullough et al., 2009a).

Notwithstanding the lack of specific regulations, key national and international mine closure guidelines recognise that sustainable mine closure requires effective stakeholder engagement. Stakeholder engagement is an inclusive process, which involves people potentially affected by the mine closure and those with an interest in its rehabilitation or future use. It requires closure information to be distributed to stakeholders in a timely and coordinated manner, and allow adequate time to respond to stakeholder requests (ANZMEC/MCA, 2000). This involves bringing together the views and knowledge of various stakeholders to achieve beneficial outcomes for the operating company and the local community (ICMM, 2008). The objective of stakeholder engagement during mine closure is to enable all stakeholders to have their interests considered before the mine is closed. Early and open company interactions with staff, shareholders and community will also assist regulators to make decisions for pit lake closure with minimum practicable risk of potential controversy.

Although many pit lakes exist and have been developed along these trains of thought, because of the non-scientific nature of many end use development processes, publication of most pit lake developments for social or environmental beneficial end uses occur predominantly within the non-scientific literature in a case-study format with little general guidance offered (Walls, 2004). Instead, factors governing the decision to develop pit lakes are either to reduce or remove impact to meet regulatory performance requirements, or to go further and develop them into a tangible environmental or social benefit. As such, factors to be considered when determining the nature of a final pit lake fall largely into either regulatory requirements or development incentives. An exception is the Western Australian "Draft guidelines for preparing mine closure plans" (DMP/EPA, 2011) which explicitly request mine closure planners for operations realising pit lakes to consider beneficial end uses in their closure plans where water quality is likely to be good.

6 Development incentives for pit lakes

There may be little regulatory or financial pressure to develop an end use benefit from a pit lake. Indeed, many mining companies, researchers and regulators themselves currently perceive regulation to often be more an impediment than an incentive to their own development of social and environmental end uses from pit lakes. Nevertheless, although there may be genuine risks associated with some end uses (Doupé and Lymbery, 2005), pit lakes are being increasingly recognised as opportunities and not just liabilities for potentially gaining benefit to their local community and environments (McCullough et al., 2009a) and particularly in arid environments (Kumar et al., 2009).

Internationally, public perception of pit lakes at abandoned, disused, or unreclaimed hard rock and coal mine sites is typically negative (MMSD, 2002; Hammond, 2010) and may even expose mining operations to more risk than relevant regulations do. Public concerns about pit lakes tend to centre on pit water quality and the possible impacts to nearby water bodies, wildlife, and sometimes even public safety (Williams, 2009). As a result, many mining companies have developed sustainable development policies that likely provide for greater protection from negative effects of pit lakes; and also for greater restoration opportunities than simple regulation does alone. These restoration attempts seek alternative reclamation options particularly for development of pit lakes that have good quality water and could enhance opportunities for sustainable development of the mining operation. In some cases, overly prescriptive regulations that are sometimes not relevant to the case-by-case situation of many pit lake closure scenarios may discourage beneficial end uses developments by directing company focus wholly upon risk. In these cases companies are encouraged to comply with meeting detailed regulatory directions rather than broadly and narratively defined closure objectives which they – together with researchers, consultants and project stakeholders – may have been better able to define.

Figure 3 Misapplied, regulation can be a major obstacle to development of innovative mine water treatment and closure scenarios. Controversially for state regulators, but with strong community support, this passive treatment field experiment in North Queensland used raw sewage as a carbon source (McCullough et al., 2008) (Photo courtesy of C.D. McCullough)

Although the target of a post-mining landscape is generally to restore the affected areas to the environment of the previous landscape (Lögters and Dworschak, 2004), this is not often practicable due to high expenses for earthworks and backfill, extended non-operational times to relinquishment, or simply that, due to the abstractive nature of mining, mined resources (waste rock, etc.) are no longer available. Consequently achieving a planned landscape of equal or even greater social and environmental value by instead using the pit lake may be one way in which the mine operation can positively contribute to a region's sustainability and meet biodiversity goals.

7 Conclusions and recommendations

Regulatory requirements governing available pit lake end use options differ between and even within different countries as a result of both different regulatory regimes and also due to the many different potential risks that pit lakes may represent to that particular region. For example, as many mines occur in remote, low rainfall regions (e.g. the Pilbara but also similar arid regions of the US and China), inappropriately managed pit lakes may represent a significant risk to the local human and environmental water resources (Brown, 2003). Where communities reside nearby, pit lakes may also present risks for recreational swimmers where there is a risk of drowning with the limited shallow margin typically afforded by them or falls from high walls that have not been battered down (Hinwood et al., 2010). This is the case even in remote areas where pit lakes are often swum in as organic recreational opportunities (Hinwood et al., 2010). In agricultural areas pit lakes such as the Pilbara may lead to poisoning and drowning of stock and wild life where there is a risk of falls from the pit high walls. In environmentally sensitive areas, mixing of local water resources with contaminated pit waters may lead to loss of biodiversity or ecosystem function (McCullough and Lund, 2006). Particularly in drier regions, pit lakes may also be an ecological liability through supporting populations of feral animals. Consequently, significant rehabilitation may be required to turn a pit lake landscape from an industrial site to an acceptable public amenity or wild life habitat (Krüger et al., 2002).

Figure 4 Mine rehabilitation regulation and closure requirements have lagged behind that for terrestrial post-mining landforms; what is no longer acceptable for above ground landforms, (top) unrehabilitated waste dumps is also becoming unacceptable to pit lakes at closure as well (bottom) unrehabilitated lake edges and poor water quality (Photos courtesy of J. May, C.D. McCullough)

A select few countries and regions do clearly regulate end uses for pit lakes. This end use choice is usually determined by existing local economic, social or environmental interests. For example, end use amenity is broadly regulated in the Lower Lusatian Lignite mining area of Germany on the basis of regional planning targets for land use for economic, environmental and social (recreation) concerns (Dähnert et al., 2004). Nevertheless, these overall strategies may be inflexible for other end uses, including more local-scale interests (Kruger et al., 2002). For instance, social amenity end uses are less commonly specified as end uses for pit lakes as these end uses are typically novel for the area.

In most countries, mining companies are given no prior advice of acceptable end use options by governing bodies. Rather, mining companies interested in developing an end use approach regulatory authorities with their preferred option and then these agencies make judgements as to whether this end use is acceptable. Nevertheless, most developed countries and states are consistent in their requirement for mining companies to plan and/or rehabilitate to minimise or prevent entirely any potential deleterious effects of the pit lake water body on regional ground and surface resources (Miller, 2002). Special regard is also especially given to protecting regional human and ecological communities from negative effects of the pit lake. For example, in Australasia, closure guidelines are based on (ANZECC/ARMCANZ, 2000) criteria (generally for a combination of, ecological and/or drinking water and recreation requirements). Such guidelines generally emphasise either a demonstration of null-negative effects of the lake, or a requirement for active management to a specific point of compliance where issues from the pit lake remain, such as poor water quality (Kuipers, 2002).

Nevertheless, where such regulatory guidelines that are normally only relevant for protection of natural systems such as natural lakes are applied to pit lakes, end use opportunities may be rendered unavailable as inappropriately high environmental and social values are placed on these artificial systems. This has occurred internationally where the water quality of a Minnesota, USA, pit lake was not permitted by state regulations to be degraded by aquaculture below that permissible in a natural lake (Axler et al., 1996, 1998).

Significantly, lack of knowledge of state-of-the-art rehabilitation strategies and capabilities, such as remediation techniques, by regulators may also produce a strong deterrent for companies wishing to engage in end use development activities; whether they be for social use or as wildlife habitat (McCullough et al., 2009b). Although it is expected that liability caused by a pit lake will be incurred until the lake is relinquished to state/federal authorities, in some of these cases mining companies have needed to incur themselves an increased risk of liability during development of a specific end use in order for beneficial end use development to be approved by regulators.

There are a wide range of general guidelines and recommended processes to allow for an initial decision-making strategy on whether it is desirable for pit lakes to form in empty mining voids in Pilbara operations. However, specific regulatory guidance specific for developing and closing pit lakes is sparse. Instead, approaches toward pit lake development have generally been made by considering every mine site as unique. As a result, current international practice has indicated through publications and interviews that development of pit lakes should, and is generally managed on a case-by-case basis. We agree and support this approach to pit lake planning and approval.

A significant guiding principle that is generally missing from regulatory statement and documents is the need to identify what target form of wetland (the restoration goal) these water bodies could and should take. Once this goal is established and comfortably articulated as fitting with broader company sustainability and biodiversity strategies, it will assist in the development of general conceptual plans for each mine sites that may form pit lakes at closure and abandonment. The next step must then be to evaluate as a gap analysis information and understanding for mine closure against this closure goal; as it is for other mining land forms lakes. Filling remaining knowledge gaps is therefore suggested as a critical focus of the pit lake development planning and process. The use of regional water bodies as reference systems to direct potential development trajectories in pit voids and also as restoration goals for developing pit void wetlands is essential. Presenting a well-developed pit lake closure plan to regulators and stakeholders would then be a near-final stage of refinement of the pit lake and broader mine closure and abandonment process.

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