The Environmental and Financial Aspects for the Use Of Pit Lakes for Sustainable Mine Closure

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Abstract

Mine closure has become an integral part of mine planning to ensure sustainable closure of mines and to avoid post closure social and environmental risks and to minimize closure financial liabilities. Opencast mining operations result in a final mine void which on closure fill with water, forming a pit lake. Pit lakes are becoming an increasingly acceptable form of mine closure provided that long-term environmental risks are acceptable especially water quality degradation. In addition, pit lakes may negate cost associated with backfilling of the final mine void and potential water treatment costs. Case studies have shown that terminal pit lakes can reduce closure costs by 50 to 85%. Sustainable mine closure is assessed in terms of the appropriate mitigation measures to ensure no long-term environmental liabilities.

Keywords: Mine closure, pit lakes, water management, financial provision

Introduction

To ensure sustainable mining, all mines require a closure plan that must be environmentally, legally and socially sustainable and is suitably funded. In assessing the environmental aspect of closure, one of the most important factors is the management of post closure water impacts and liabilities. The potential post closure water impacts are dependent on the mining method and the mineral being mined. In general, sulfide ores have the greatest impact on water quality and open cast mining the largest impact on water quantity. Sulfide ores often lead to acid mine drainage as seen in copper mines in Canada and Spain. Pit lakes are an internationally acceptable from of mine closure for example lignite mines in Germany, gold pits in Australia and sulfide mines in Canada.

The main concern regarding potential water impacts on the closure of a mine is determining the impact of rebounding water. The forecasting is required to determine if the rebounding water will discharge on surface. If the rebounding water will discharge on surface predictions are required to determine the time, location, volume and the quality. The water management strategy is then included in the mine closure plan and budgeting the financial provision for the rehabilitation quantum.

Pit lakes form when dewatering ceases and mine voids fill with water. Correctly designed pit lakes provide a sustainable water management option for mine closure and may avoid long-term treatment costs. Correctly designed pit lakes minimise environmental impact and long-term post closure financial liabilities. Pit lakes also offer potential uses of the water for domestic, off channel storage, agriculture, fish farming, recreation and biodiversity. (Blanchette and Lund 2016).

The aim of the paper is to evaluate pit lakes as a cost effective, environmentally sustainable closure option through South African case studies. The paper discusses 4 case studies for the closure of a coal, diamond, chrome and a manganese mine in South Africa using pit lakes

Types of Pit Lakes

There are three main types of pit lakes, and these are largely dependent on the hydrological regime and the pit lakes water balance. (See Fig. 1).

Type 1: Terminal sinks have no surface outflow due to a net negative water balance

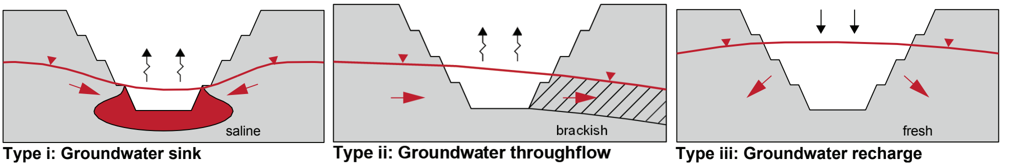

Figure 1 Sink, Throughflow and Recharge Pit lakes (Johnson and Wright 2003).

Type 2: Throughflow pit lakes result in flow of groundwater from the pit lake Type 3: Recharge pit lakes result in groundwater recharge and potential discharge on surface

South African Climate

South Africa's climate varies from a humid climate in the southeast to very arid in the west. In general, the decrease in rainfall is associated with an increase in the potential evaporation resulting in a net water deficit over the majority of South Africa. On average South Africa receives 500mm/a with a mean potential evaporation of 1800mm/a. The magnitude of the water deficit depends on the location in South Africa and offers the opportunity for the design of terminal sink pit lakes as a closure option. This relationship applies to many global locations including Australia, Chile and West Africa. Terminal sink pit lakes offer an alternative to long term water treatment with the associated carbon footprint and disposal of waste.

Pit lake Water Balance

Pit lake water balances in South Africa are largely controlled by evaporation as evaporation exceeds precipitation by a factor of 2 to 3 (depending on the location). As a result, if the inflow into a pit lake is managed and the net evaporation from the pit lake surface area is greater than the sum of the inflows, it is highly unlikely that the pit lake will discharge onto the surface and into the catchment. This deficit in arid climates support terminal sinks reducing discharge risks as seen in wetter climate like Scandinavia and Germany. The water balances of the pit lakes are calculated based on a generalized mathematical expression after Gamons *et al.* (2009) where:

$\Delta S = (P + SWin + GWin) - (E + (T) + SWout + GWout)$

ΔS is change in storage, which is the volume of water in the lake.

Water In is a sum of:

P is the precipitation falling onto the pit lake.

SWin is the sum of any surface water inputs which include runoff and diverted streams.

GWin is groundwater entering the lake (which includes groundwater flow from historical workings).

Water Out:

E is the evaporation from the lake.

T is plant transpiration (negligible in arid pit lakes and significant in wetter climates)

SWout is surface water discharged from the pit lake and includes pumpage.

GWout is the groundwater leaving the pit lake.

In the above equation if **SWin** is managed by minimizing runoff into the pit lake and **GWin** is reduced by allowing groundwater levels to rebound decreasing the groundwater gradient (inflow) and evaporation exceeds the sum of all inflows into the pit lake, the pit lake will be a terminal sink. SWin can be minimised inflow management techniques such as diversion channels to discharge clean water into the catchment. The arid climatic conditions in southern Africa favour the use of terminal pit lakes for mine closure.

Pit lake Water Quality

A major consideration is the pit lake water quality after the closure of the mine. The pit lake water quality affects the environmental classification and as a result the environmental sustainability of the lake. Models of pit lake geochemistry are described by external and internal processes of which many of the internal processes are mediated by algae and microbes (Gammons *et al.*, 2009). External processes are described as wall rock runoff and wall rock leaching in the Kriel case study detailed below. The quality of the inflows (surface and groundwater) into the pit lake also affects the evolution of the pit lake water quality (See Fig. 2)

Pit lakes generally exhibit stratification in the water column which is also dependent on the depth of the pit lake. Shallow pit lakes exhibit less stratification than deep pit lakes. The stratification results in a variation in the water quality and temperature with depth (Gammons 2009). The aspect ratio of pit lakes determines the relationship between the surface area and depth of the pit lake (Castendyk *et al.* 2015). Shallow lignite pit lakes in Germany exhibit very little stratification and due to wind related mixing (Muller 2017) while deep pit lakes in Navada form meromictic layers. Fig. 2 shows the varying water quality and geochemical process that occur in pit lakes in the epilimnion, hypolimnion and monimolimnion.

Considerations for Using Pit lakes as a Sustainable Closure Option

Assessing a mine closure plan that includes pit lakes requires evaluating, quantifying, and prioritising various factors to determine their suitability for sustainable closure (ICMM, 2019). Water quality is typically the most critical consideration.

South African Regulatory Requirements

South Africa has a complex regulatory framework for the use of pit lakes in mine closure. The regulatory requirements include the Mineral and Petroleum Resources Act 28 of 2002 (mandates mine closure), National Water Act 36 of 1998 (mandates water licences) and the National Environmental Act 107 of 1998 (mandates ESIA). To obtain the regulatory approval for the use of pit lakes in the mine closure multiple authorisations are required for all the acts. A working group involving Coaltech, Minerals Council and some mining companies are engaging with the relevant South African Authorities to streamline the process for the approval of pit lakes for mine closure. Unlike Australia's streamlined EIS process, South Africa requires multi-act approvals and draft regulations are expected in late 2025

Case Studies

To illustrate the implementation of pit lakes into mine closure programs several South African case studies are discussed. As each pit lake is unique but is governed by the same broad classifications and the author has selected several case studies to illustrate various options. The case studies are included in the mine closure plan and the associated financial provision. Only in the diamond and one of the coal mines cases have the mine closed, while in all the other case studies involve operational mines. The case studies vary in locations, nature of the ore body,

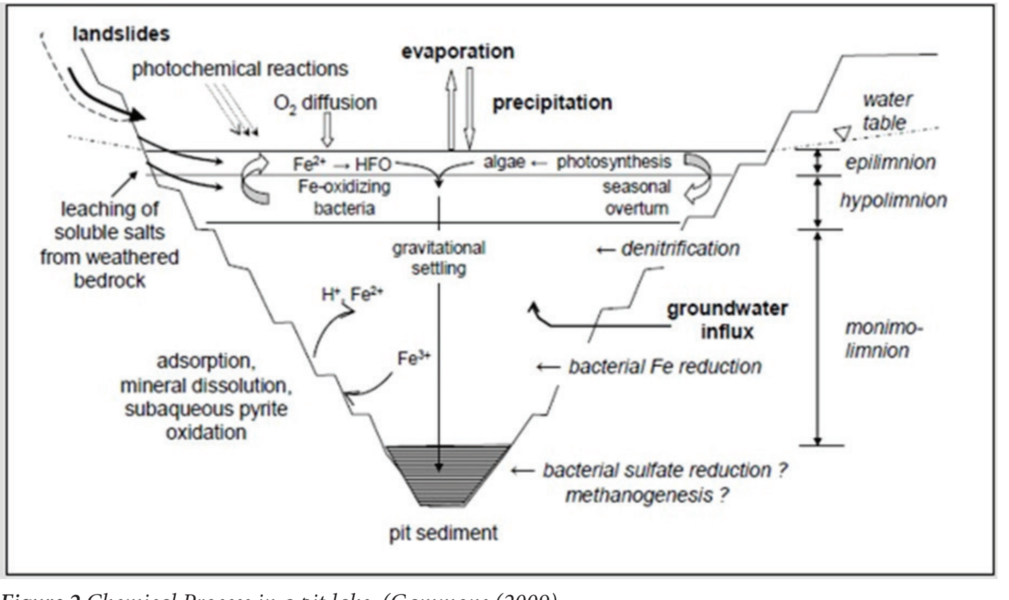

Figure 2 Chemical Process in a pit lake. (Gammons (2009).

Table 1 Factors to be considered regarding the use of pit lakes as a mine closure option.

Water quality, stratification, mixing	Long-term treatment liabilities	Post-mining employment	Site water balance
Mine water management	Catchment resources	Hydrology and hydrogeology	Geochemistry
Integrated closure planning	Microbiology	Pit lake bathymetry	Licensing and legislation
Biodiversity	Closure cost reduction	Social impact	
Health and safety	Alternative land use	Site water balance	

environment, social and financial aspects. The following case studies from different mining environments are discussed for a Coal, Diamond, Chrome & Manganese Mine in South Africa

Case Study 1: Coal Mine Pit lakes

The case study involves a study of three pit lakes in various coal basins in South Africa with different mining methods and climatic regimes. The studies were funded by the South African Water Research Commission and details are detailed in WRC publications K5/2577//3 (2019) and TT 797/2/19 (2019) and Coaltech (2021).

In general coal mines and spoils have the potential to generate poor quality leachate and acid rock drainage. Closure plans are required to management of the post closure liabilities, especially the water impacts and associated liabilities. The three mines investigated were:

- Mafuta Mine is situated in the Waterberg coalfield and is a single pit. The pit lake is a terminal sink
- Kriel Colliery is situated in the Mpumalanga coalfield and the comprised roll over open cast mining with a final void. The pit lake is a terminal sink
- Rooikop Mine in the KwaZulu-Natal coalfields and was open cast mine with underground operations developed from the high wall. The pit lake discharges onto surface during the summer rainfall months

In all cases the pit lake water was neutral to alkaline, and the total dissolved solid (TDS) content varied depending on the mining method. The highest TDS (3443mg/L) was recorded in pit lakes resulting in the role over method where the pit lake was in direct hydraulic contact with the backfilled material. The lowest TDS (1000mg/L) was recorded in the single open pit and intermediate TDS (1208mg/L) where the pit lake was in direct hydraulic contact with underground operations (Table 2). These are pit lake water quality where water levels have stabilized. Variable pit lake water quality can be expected during the rebound of water levels and before a steady state as in the case of Kriel. In all cases regulatory exemption is required as the pit lake does not comply with catchment water quality standards and all cases supports aquatic life.

Case Study 2: Diamond Mine Pit Lake

The diamond mine case study where a pit lake in included the mine closure plan is a single pit open cast mine. When mining ceased in the late 2010’s groundwater levels were allowed to rebound in the open pit. Pit lake water levels and quality are monitored

Table 2 Coal mine Pit Lake Water Quality .

Pit lake	Mafuta	Kriel	Rooikop
pH	8.4	8.4	7.9
TDS (mg/L)	1000	3443	1208
Sodium (mg/L)	301	434	18
Total Alkalinity (mg/L)	326	197	118
Sulfate (mg/L)	94	1930	608
Chloride (mg/L)	314	35	2.5
Nitrate- NO_3 (mg/L)	9.7	0.24	<0.1

regularly and do not comply with catchment water quality standards (Table 3). The pit lake water balance was calculated and is a terminal sink. A cost comparison was completed where the cost of backfilling the open pit was compared to the use of a pit lake in the closure planning. The orders of magnitude for backfilling of the open pit are R3.4 billion compared to an estimated R500 million if the pit lake is accepted as a closure option. The closure costs of the pit lake option include revegetation of waste/spoils, storm water diversions, slope benching and fencing to address safety concerns.

The major considerations against the pit lake closure option were pit side wall stabilities, sterilisation of resource with backfilling and loss of some 20 ha of arable land. Studies proved that the pit lake closure option was environmentally sustainable, financially preferable and potential safety concerns could be mitigated. At present, the mine is undergoing extensive applications for regulatory approval.

Case Study 3: Chrome Mine Pit Lake

The case study involves a large open cast chrome mine in the Western Bushveld Igneous Complex of South Africa. The mine plans to develop an underground extension from the open pit high walls. During the underground development, the mine will leave the associated waste in the open pit. Geochemical assessment of the chrome seams, roof, floor and overburden proved that lithologies are largely inert and do not pose any risk of water contamination (ABA results less than 0.5% S). During the closure planning, numerous post mining land uses were identified, feasibility studies undertaken and costed. One of the post closure land uses is to use the pit as a water resource where storm water and other sources of water could be stored and used during winter to meet regional domestic demand. Other potential post closure land uses involved agricultural irrigation, out of pit fish farming and recreation. The financial provision for backfilling of the open cast was calculated to be R5.5 billion compared to an estimated R1 billion for the use of a pit lake for closure.

Case Study 4: Open Cast Manganese Mine

The manganese mine is in the arid Northern Cape Province of South Africa. The current mine closure plan states that the open pit should be rehabilitated with backfill. Detailed geochemical assessments to determine the risk of acid rock drainage and generation of poor-quality leachates identified no risks from the pit, waste and overburden rock dumps other than nitrate from the explosives. Due to the climate of the area and the hydrogeological regime, the pit lake would be a terminal sink. The water quality in the pit lake would decline over time due to evapo-concentration of salts in the pit lake (Table 5). Case studies modelled in the arid USA the indicate that pit lake salt concentrations are likely to double every 50 years. In the case of terminal sink pit lakes, the groundwater gradients are into the pit lake posing no thread to the surrounding land use largely game and stock farming with a low population density and land value. The zone of impact of the terminal pit lake on the surrounding groundwater users is limited

Table 3 *Diamond Mine Pit Lake water quality.*

	Pit lake (2017)	Ambient Groundwater (April 2017)
pH	7.1	7.9
TDS (mg/L)	1934	615
Electrical Conductivity (mS/cm)	294	102
Sodium (mg/L)	432	53
Total Alkalinity as $CaCO_3$ (mg/L)	1403	480
Sulfate (mg/L)	44	27
Chloride (mg/L)	242	33
Nitrate as N (mg/L)	0.1	0.25

Table 4 Summary of Groundwater Quality for Open Pit Chrome Mine.

Constituents of Concern	Prediction of pit lake water quality (2050)
pH	7 to 8
Total dissolve Solids mg/L	500 to 640
Sulfate (mg/L)	80 to 100
Nitrate as N (mg/L)	20 to 30

(Water quality will vary depending on supplementary sources of water to be stored in the pit lake)

due the low aquifer potential The side wall of the open pit would be sloped for safety to the groundwater rebound level.

Conclusions

The use of correctly designed pit lakes will result in sustainable mine closure. Pit lakes offer various benefits including but not limited to water management, biodiversity, alternative land uses, post mining employment and an overall reduction in closure cost. Post closure water management benefits of pit lake are the control of surface discharge, avoidance of long-term water treatment costs and the associated carbon footprint, plus alternative uses for the water resource. Pit lakes also offer potential to increase both the aquatic and terrestrial biodiversity of a historical mined area. Pit lakes result in a reduction in closure liabilities when compared to backfilling of the open pit and long-term water treatment of up to 85% in the diamond mine case study and 80 % in the chrome mine case study. The author would like to stress that the potential use of pit lakes as a closure option must be included in the mining feasibility study to allow for the correct pit lake designs. The inclusion of pit lakes in the closure plan will decrease regulatory delays and compliance with ICMM Closure goals

References

Coaltech (2021) GCS Water and Environmental (Pty) Ltd and Gunn Attorneys. A Manual for the Authorisation of Pit Lakes as a Closure Option for South African Coal Mines.

Gammons CH, Harris LN, Castro JM, Cott PA, Hanna BW (2009) Creating Lakes from Open Pit Mines: Processes and Considerations, Emphasis on Northern Environments.

International Council on Mining & Metals (2019) Integrated Mine Closure Good Practice Guide.

Johnstone AC, Kennedy L, Mpetle M (2019) An Investigation to Determine if South African Coal Mine Pit Lakes are a Viable Closure Option. Water Research Commission Report No. 77 797/1/19 Vol 1.

Johnson K, Wright P (2003) Hydrological Classification of Pit Lakes.

Blanchette ML, Lund MA (2016) Pit Lakes are a Global Legacy of Mining: An Integrated Approach to Achieving Sustainable Ecosystems and Value for Communities. Sci Total Environ.

Lund MA, Blanchette ML (2023) Closing Pit Lakes as Aquatic Ecosystems: Risk, Reality, and Future Uses.

Müller M (2013) Modeling Pit Lake Water Quality – How Do We Solve Multi-Disciplinary Problems? IMWA.

WRC (2019) GCS Water and Environmental (Pty) Ltd. A Preliminary Manual for the Design of Coal Mine Pit Lakes as an Environmentally Stable Closure Option in South African Mines.

Table 5 Results of Predicted Water Chemistry for 100 years (Concurrent Backfill and Pit Lake Formation).

Constituents of Concern	Initial	100 years
pH	8.9	7.0
Total Dissolved Solids (mg/L)	1365	5 460
Sulfate (mg/L)	127	508
Nitrate as N (mg/L)	15	60