

# Are Pitlakes an Environmentally Sustainable Closure Option for South African Coal Mines? ©

Andrew Johnstone

*GCS (Pty) Ltd, Rivonia South Africa, andrewj@gs-sa.biz*

## Abstract

There are over 200 pitlakes in South Africa due to over two centuries of coal mining. The aim of this study is to determine if pitlakes are a sustainable coal mine closure option in South Africa. The study investigated the water balance, chemistry, limnology and bacteria of three selected pit lakes. The pitlakes occur in the three major coal basins of South Africa and are as a result of different mining methods. The major factors driving the water balance of the pitlakes are rainfall, runoff, groundwater and inflow from historical mine workings. The major losses from the pitlakes are evaporation or discharge of water on surface. The study proved that pitlakes can be designed to be terminal sinks and as a result a sustainable closure option in terms of the water balance. The groundwater chemistry showed the pitlakes to be stable with alkaline pH, mostly a sodium sulphate type water with total dissolved solid content of less than 3 000mg/L. The phytoplankton and microbiological data showed that the pitlake supported aquatic life. The study proved that with the correct design, coal mine pitlakes are an environmentally sustainable closure option for South Africa coal mines. A suggested design manual was developed to aid mine planners, owners and regulators to develop sustainable coal mines pitlakes as a closure tool.

## INTRODUCTION

South Africa has been mining coal since the early 1800's initially by conventional underground methods, but since the 1950s, the majority of the coal production has been from open cast mines. Coal supplies 95% of the South Africa's power supply and this is predicted to continue into the latter half of the 21<sup>st</sup> century. South African coal production for power generation, export and domestic consumption is estimated at 255 million tonnes per annum. Open cast coal mines generally leave a final void because of the mining method, insufficient overburden to fill the voids created by removal of the coal and /or to manage water. Once mining operations cease these voids fill with water forming a lake which is generally referred to as a "pitlake". The author has estimated that there are over 200 pit lakes in the three major South African coal fields namely the Witbank, Kwa-Zulu Natal and Waterberg Coalfields. The study evaluates the environmental sustainability of using pitlakes as a closure option for existing and proposed new coal

mines in South Africa.

The major factors that determining environmental sustainability of pitlakes are the water balance and water quality. Positive water balances result in discharge of water from the pitlake onto surface. A further environmental sustainability consideration is the chemical and biological nature of the water in the pitlake. Pitlake water quality varies depending on the geology, mining method and catchment characteristics. In general, pitlake water quality may not comply with legislated catchment water quality standards resulting in potential threats to the overall catchment water quality. This investigation concentrated on the two major drivers of pitlake sustainability, whilst investigating 3 different pitlakes.

The pitlakes studied were selected on the basis that they are representative of the major South African coal fields considering variances in geology and climatic conditions. The factors affecting pitlake water balances (and as a result the variation in water levels) are groundwater, direct rainfall and

runoff, while the losses from the pitlakes are evaporation, surface discharge and flow into the surrounding aquifers. The water balances of each of the pitlakes were evaluated to determine the major inputs and losses. The major input free draining rehabilitated mines was found to be groundwater either from the aquifer or backfilled material. To a lesser extent water balance inputs were from runoff and direct rainfall. The major losses from the pitlakes was found to be evaporation. Pitlake morphology, volumes and surface area are the major design considerations to prevent discharge of pitlake water into the catchment. The chemical and biological evolution of the water quality in a pitlake determines the long-term ecological sustainability of pitlakes. The chemistry study concentrated on the water quality and vertical stratification. The vertical variation in pH, temperature, dissolved oxygen and the redox potential was measured at numerous points in each of the pitlakes. The organic study determined the phytoplankton, chlorophyll *a* and the microbiology of each of the pitlakes.

The outcome of this study is that pitlakes can be environmentally sustainable if they are designed correctly and that the potential to discharge water into the catchment area is managed. The organic and inorganic water quality in the pitlakes showed that the pitlakes are alkaline and have elevated total dissolved solid contents (mainly calcium sulphate) when compared to the natural surface and groundwater in the catchment. The pitlakes support life in terms of chlorophyll-*a*, phytoplankton, microbiology (bacteria), vegetation and aquatic life

The current South African mining and environmental legislation states that all pitlakes should be backfilled for the mine to achieve closure. This has considerable financial liabilities for old and ownerless mines, closed mines and current operations. Environmentally stable pitlakes offer a sustainable closure option and may avoid the expense of continual water treatment. A fundamental change in the current South African legislation is required to accept pitlakes as an environmentally sustainable solution. Enough data was collected in the study to allow for the development of a guideline

for the design of coal mine pitlakes in the Southern African coal fields.

## PITLAKE WATER BALANCES

Pitlake water balances in South Africa are largely controlled by evaporation as evaporation exceeds precipitation by a factor of 2 to 3. As a result, if the inflow into a pitlake is managed it is highly unlikely that it will discharge onto surface and into the catchment. The water balances of the pitlakes were calculated based on a generalized mathematical expression after Gammons et al., (2009)

$$\Delta S = (P + S_{Win} + G_{Win}) - (E + T + S_{Wout} + G_{Wout})$$

Where  $\Delta S$  is change in storage which is the volume of water in the lake,  $P$  is the precipitation falling onto the pit lake,  $S_{Win}$  is the sum of any surface water inputs which includes runoff and diverted streams,  $G_{Win}$  is groundwater entering the lake (which includes groundwater flow from historical workings),  $E$  is the evaporation the lake,  $T$  is plant transpiration which is often negligible,  $S_{Wout}$  is surface water discharge from the pit lake and includes pumpage,  $G_{Wout}$  is the groundwater leaving the pit lake. In the above equation if  $S_{Win}$  is managed by minimising runoff into the pitlake and  $G_{Win}$  is minimised (by allowing groundwater levels to rebound). If evaporation exceeds the sum of all inflows into the pitlake and the pitlake will be a terminal sink.

## PITLAKE WATER QUALITY

A major consideration is the final pitlake water quality after the closure of a mine. The pitlake water quality effects on the environmental classification and as a result the environmental sustainability of the lake. Conceptual 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. The quality of the inflows into the pitlake also effects the evolution of the pitlake water quality. Figure 1 summarises the processes that determine the chemistry in pit lakes.



*Plate 1: Mafutha Pitlake: (September 2018).*



*Plate 2: Kriel Pitlake 4: Ramp 44 North, looking North, 29 March 2017.*

## CASE STUDIES

This study concentrated on 3 case studies namely Mafutha, Kriel and Rooikop pitlakes and the characteristics of the pitlake are shown in Tables 1 and 2 and Plates 1, 2 and 3

Mafutha is single open pit where 250 000 tons of material was removed from a single 90m deep open pit. The pit is surrounded by an undisturbed aquifer and surface runoff into the pit is largely to runoff from the side walls. The pitlake has reached equilibrium where groundwater inflow and direct rainfall equal evaporation resulting in very minor seasonal variations in pitlake levels. The pitlake water in Mafutha is alkaline with a

TDS of 1 000mg/L sodium chloride water.

The Kriel site comprises several hydraulically linked open pits due to extensive extent of the open cast mining. The pitlakes are hydraulic connection due to the highly permeable backfilled open cast material between the lakes. In this system the major inflows are due to direct rainfall, runoff and substantially greater recharge through the overburden spoils. Inflow exceeds evaporation and groundwater outflow, resulting in periodic outflow onto surface. The pitlake water is alkaline with a TDS of 3 500mg/L and is largely a sodium calcium sulphate water.

The Rooikop pitlake is hydraulically connected to the underground workings. Inflow is from groundwater recharge to the 100ha underground workings. The other major component of inflow is direct rainfall and runoff. The pitlake is alkaline with a total dissolved content of 1 200mg/L and water is

calcium sulphate. The pitlake has a positive water balance and outflow occurs in the subsurface along the coal seam into pollution control dam which then discharges into a stream. The discharge into the stream does not comply with the water quality objectives of the stream.

Table 1: Pitlake Physical Characteristics

	Mafutha	Kriel	Rooikop
Coalfield	Waterberg	Witbank /Mpumalanga	Natal
Nature of pitlake	Deep single open pit	Multiple hydraulically connected	Single lake connected to underground workings
Mining method	Bulk sample	Open cast roll over method	underground bord and pillar
Age yrs.	8	Operational for last 13 years	12
Surface Area (m2)	26 600	272 530	17 100
Pitlake Volume (m3)	505 800	797 071	86 681
Dominant inflows	Groundwater and rainfall	Groundwater, rainfall and runoff	Groundwater from underground mine workings and runoff
Dominant outflows	Evaporation	Evaporation	Discharge and evaporation
Morphology (%)	38.4	3,2	6.8
Depth (m)	70	7	10



Plate 3: Rooikop Pitlake Nov 2017.

**Table 2: Comparison of pit lake chemistry, phytoplankton and microbiology (2016-2017)**

Pit lake	Mafutha	Kriel	Rooikop
pH	8.4	8.4	7.9
Temperature (°C)	27.2 (epilimnion; summer) 18.6 (hypolimnion, summer) 18.6 (whole pit lake, winter)	20.6 (summer) 13.5 (winter)	20 (summer) 15.3 (winter)
Dissolved oxygen (mg/ℓ)	7.53 (Epilimnion summer) 1.3 (hypolimnion summer) 6.95 (whole pit lake winter)	R44: 2.03 (summer) & 5.7 (winter) R42: 4.9 (summer) & 8 (winter)	8.3 (summer) 7.9 (winter)
TDS (mg/ℓ)	1000	3443	1208
Total Hardness (as mg/ℓ CaCO <sub>3</sub> )	186	1210	712
Sodium (mg/ℓ)	301	434	18
Total alkalinity (mg/ℓ)	326	197	118
Sulphate (mg/ℓ)	94	1930	608
Chloride (mg/ℓ)	314	35	2.5
Nitrate-NO <sub>3</sub> (mg/ℓ)	9.7	0.24	<0.1
Water type classification	Na-Cl	Na/Ca-SO <sub>4</sub>	Ca-SO <sub>4</sub>
Chlorophyll-a (µg/ℓ)	2	10.5	3.7
Trophic state classification	Oligotrophic	Mesotrophic to Eutrophic	Oligotrophic to Mesotrophic
Phytoplankton (Dominating Phylum, Genus)	Chlorophyta, Ankistrodesmus	Cryptophyta, Cryptomonas and Chlorophyta, Ankistrodesmus	Chlorophyta, Chlorella
Phytoplankton (Dominating Phylum, Genus)	Chlorophyta, Ankistrodesmus	Cryptophyta, Cryptomonas and Chlorophyta, Ankistrodesmus	Chlorophyta, Chlorella
Microbes (Dominating Phylum; Genera)	Proteobacteria; <i>Acinetobacter</i> , <i>Synechococcus</i>	Proteobacteria; <i>Hydrogenophaga</i> , <i>Chlorobaculum</i> , <i>Pseudomonas</i> , <i>Nodularia</i>	Bacteroidetes; <i>Flavobacterium</i> , <i>Luteolibacter</i>
Stratification & mixing	Strong thermal stratification (October to March/ April) Turnover (late autumn/ winter)	Weak thermal stratification (October to March/April) Turnover (late autumn/ winter)	Weak thermal stratification (October to March/April) Turnover (late autumn/ winter)
Classification <sup>b</sup>	Slightly alkaline, low TDS, Holomictic, monomictic	Slightly alkaline, high TDS Holomictic, monomictic	Circum-neutral, low-TDS Holomictic, monomictic

<sup>a</sup> Trophic state classification according to De Lange et al. (2018). Only September data for Rooikop and Kleinfontein.

<sup>b</sup> Classification of pit lakes according to Eary (1999) and Bohrer and Schultze (2008)

### Piper Diagram Pit Lakes

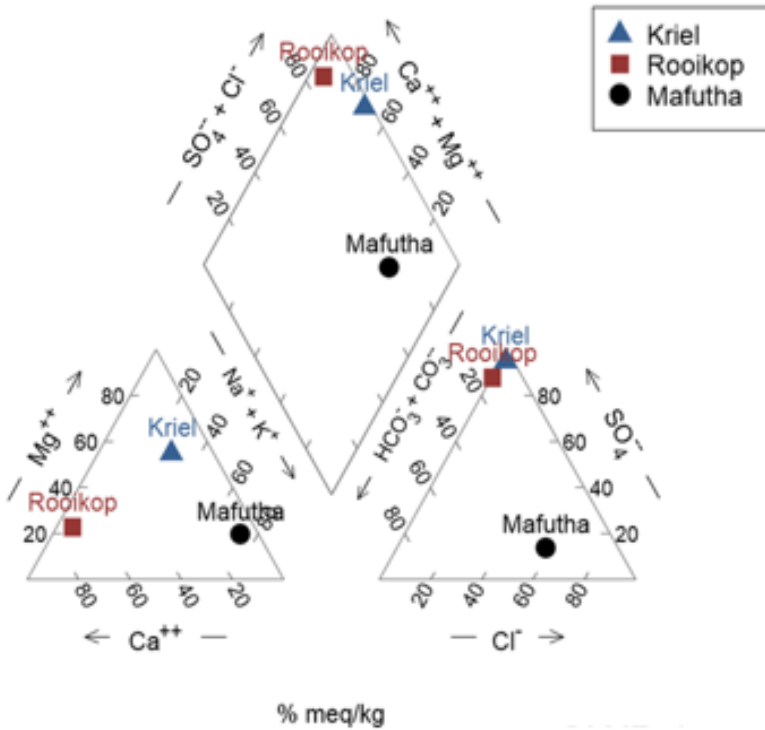


Figure 1 Piper Diagram of Pitlake Water Quality

The chemistry of the three pitlakes is shown in Figure 1.

### DISCUSSION

The pit shape is important from a water balance and water quality point of view based on the following reasons:

- Large surface area compared to mean depth, linear/ elongated pit lake morphology. These pit lakes are more prone to effects of evaporation and evapo-concentration. Larger surface areas provide larger areas for evaporation, with lower potential for discharge/ overflow and ensure a groundwater gradient towards the pit lake, to act as a hydrological sink. This is evident in the Mafutha pitlake where the pitlake is in equilibrium between inflow and outflows. See Figure 2.
- Small surface area to mean depth ratio or cone shaped pit lakes. These pit lakes

tend to form an isolated bottom layer, called the monimolimnion, with inferior water quality to the rest of the lake. If the chemistry and physical structure of the pit lake is stable, the isolated layer may be beneficial to detain potentially toxic metals. Conversely, an isolated layer may not be desirable, as sudden storms events may erode the chemocline and cause this layer to turnover together with the top layers, and mix poor, metal rich water through the whole water column with deleterious effects on overall water quality.

### ARE SOUTH AFRICAN COAL MINE PITLAKES AN ENVIRONMENTALLY SUSTAINABLE CLOSURE OPTION?

The use of pitlakes in the South African coal mine as an environmentally sustainable closure option must consider the following aspect which should be incorporated into the closure design.

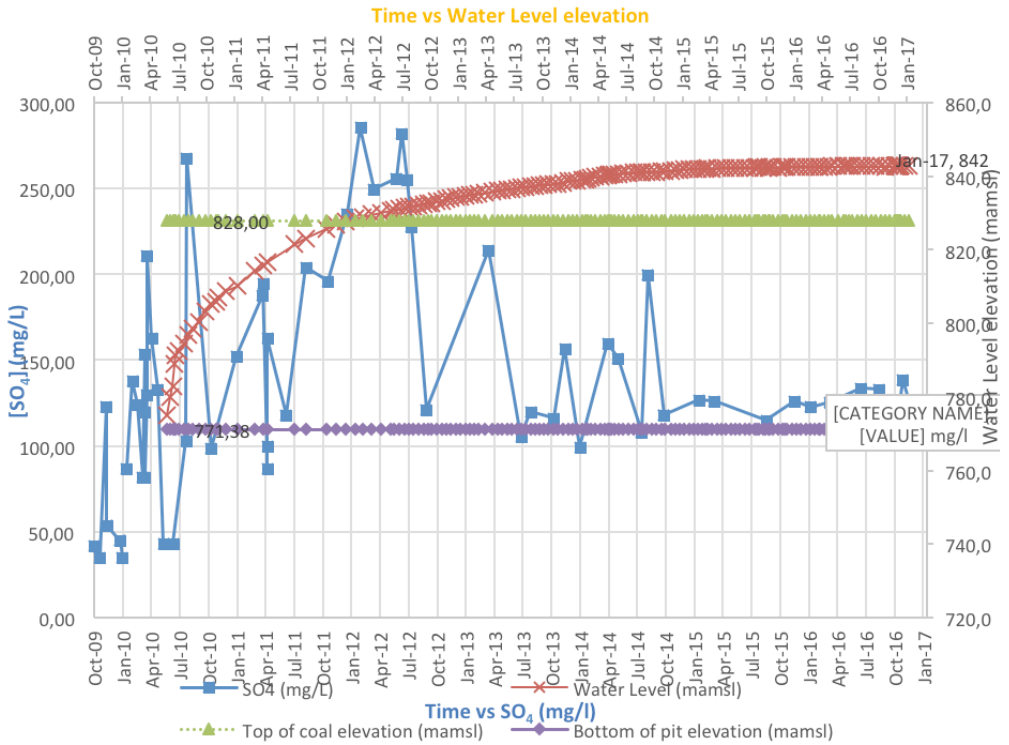


Figure 2 Mafutha Pitlake: Water level rebound and chemistry

**Water Balance**

It is critical that the sum of the inflows into the pitlake is less than evaporation to prevent major changes in pitlake water levels. Positive pitlake water balances result in discharge onto surface. Negative water balances result in pitlake being a terminal sink. As a result, a carefully designed pitlake where the inflows equal the outflows will result in a stable pitlake which will not discharge onto surface. The morphology is a critical factor in determining the environmental sustainability of a pitlake.

**Water Quality**

The South African pitlake studied are all alkaline with variable dissolved solids contents which support phytoplankton, microbes, vegetation and aquatic life. Although the water quality may not comply with the catchment water quality objectives, the pitlake is environmentally sustainable.

Pitlakes are an environmentally sustainable closure option in South Africa if designed to have a marginally negative water balance to act as a sink. The water quality

**Summary of Pitlake water balances**

Pitlake	Inflow	Outflow
Mafutha	Groundwater 90% Runoff 2% and direct rainfall 8%	Evaporation 100%
Kriel (average of 4 pitlakes)	Groundwater 43% runoff 17% direct rainfall 40%	Evaporation 100% for most years
Rooikop	Groundwater 58%Runoff 11 %direct rainfall 37%	Evaporation 90% discharge 10%

shows that the pitlakes are stable and able to support aquatic life.

## CONCLUSION

The surface area of a pitlake is vitally important in order to maximise evaporation which directly affects the water balance. In addition, surface runoff should be controlled to avoid excess flow into the pitlake during storm events that may lead to a temporary positive water balance and uncontrolled discharge into the catchment. Should the pitlake to suitably design it forms a water sink to prevent uncontrolled discharge from the mining operations.

The water quality in the pitlakes are alkaline with evaluated dissolved solid content but is able to support chlorophyll-a, phytoplankton and bacteria. Although this may not comply with catchment water quality standards is support a stable ecosystem.

Correctly design coal mine pitlakes are a sustainable closure option for South African coal mines in South Africa. It is recommended that the current South African legislation be reviewed in order to accommodate pitlakes as a sustainable closure option.

## REFERENCES

- BOEHRER B and SCHULTZE M (2008) Stratification of lakes. *Reviews of Geophysics.*, 46, 2005, doi:10.1029/2006RG000210.
- CASTENDYK DN, EARY LE and BALISTRIERI LS (2015) Modelling and management of pit lake water chemistry 1. *Theory Applied Geochemistry* 57 267-288.
- CASTENDYK DN and EARY LE (2009) The Nature and Global Distribution of Pit Lakes. In: CASTENDYK D., E. L. E. (ed.) *Mine Pit Lakes Characteristics, Predictive Modelling and Sustainability*. Society for Mining, Metallurgy and Exploration.
- DOYLE GA and RUNNELLS DD (1997) Physical limnology of existing mine pit lakes. *Mining Engineering*, 49, 76-80.
- DE LANGE WJ, GENTHE B, HILL L and OBERHOLSER PJ (2018) Towards a rapid assessment protocol for identifying pit lakes worthy of restoration. *Journal of Environmental Management*, 206, 949-961.
- EARY E (1999) Geochemical and Equilibrium trends in mine pit lakes. *Applied Geochemistry*, 14, 963-987.
- GAMMONS C H, HARRIS LN, CASTRO JM, COTT PA and HANNA BW (2009) *Creating Lakes from Open Pit Mines: Processes and Considerations, Emphasis on Northern Environments*.
- HUISAMEN A and WOLKERSDORFER C (2015) Modeling the hydrogeochemical evolution of mine water in a decommissioned opencast coal mine. *International Journal of Coal Geology*, p 1-10. DOI: <http://dx.doi.org/10.1016/j.coal.2016.05.006>
- SCHULTZE M (2012) The filling and remediation of pit lakes in former open cast lignite mines. PhD Thesis, Technical University of Carolo Wilhemina, Braunschweig.
- SNYMAN CP (1998) Coal. In: Wilson MGC and Anhaeusser CR (Eds), *The Mineral Resources of South Africa*, sixth ed, Handbook 16, Council for Geoscience, Pretoria.
- VANDERBERG J, MCCULLOUGH C and CASTENDYK D (2015) Key issues in Mine Closure Planning Related to Pit Lakes. *Proceedings of 10th International Conference on Acid Rock Drainage and IMWA Annual Conference*, 1-10.
- WETZEL RG (2001) *Limnology: Lake and River Ecosystems*, third ed. Academic Press, San Diego, California, 1006 pp.