Viability of converting a South African Coal Mining Pit Lake System into a Water Storage Facility

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Abstract
Coal opencast pit-lake water in South Africa is not normally used for drinking water, because of poor water quality. A multi-disciplinary team investigated the viability of pumping water from an adjacent river system into neighbouring opencast voids to create an artificial pit-lake storage system that could provide water for human consumption. This paper summarises results of an ongoing investigation that involved determining water availability in the local river, supplementing inflows into the pit lake, and an assessment of likely water qualities in the pit-lake. Results are promising, as this initiative will both increase the reliability of water supply to the local community and save costs in closing the mine.

Keywords: coal mining, dynamic water balance, geochemistry, pit lake, water supply

Introduction
South Africa is largely a semi-arid country where water is very scarce. During droughts there is little water available in river and streams for long periods of time. The Constitution of South Africa states that everyone has the right to have access to sufficient water and requires that reasonable legislative and other measures be taken to provide sufficient potable water to communities. A local municipality located near the Somkhele Anthracite Mine (Somkhele) in the KwaZulu-Natal Province experiences serious water shortages. Only 69% of people in this municipality have access to potable water (Mtubatuba Local Municipality 2017). When surplus water is available in the nearby Mfolozi River, there is potential to store water in mined-out open pit voids, creating a pit-lake storage system and later treat the water for human consumption at a neighbouring Water Treatment Plant (WTP).

The proposed pit lake storage system would consist of 3 linked pits: North Pit 1, North Pit 2 and South Pit. Pumping of water from the Mfolozi River towards either the South Pit or the North Pit 1 is proposed. This pit lake system can function as a balancing dam, which provides water during drought periods. Rapid flooding of the pit like system and a constant fresh water intake from the Mfolozi River will inhibit oxidation of remaining sulphide mineralisation and maintain good water qualities in the pit lake system.

Methods
Water availability in the proposed North Pit 1, North Pit 2 and South Pit-lake system with added water pumped water from the Mfolozi

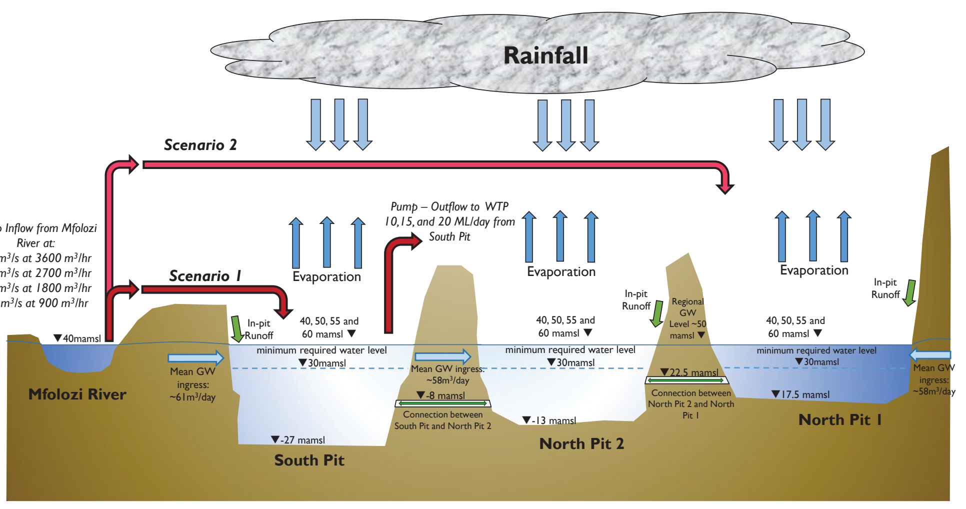


Figure 1 *Conceptual Layout of Pit-lake System.*

River was simulated. A probabilistic pit-lake water balance model was set up using GoldSim® software. Two (2) pumping scenarios, as depicted in Figure 1 were investigated:

- Scenario 1: water is pumped from the Mfolozi River straight into the South Pit; and
- Scenario 2: water is pumped from the Mfolozi River straight into the North Pit 1.

In addition to pumping scenarios, different Full Supply Level (FSL) operating levels (namely 60 metres above mean sea level (mamsl), 55 mamsl, 50 mamsl and a conservative level of 40 mamsl) in the pit lakes were investigated, together with different levels of water supply (10 ML/d, 15 ML/d and 20ML/d) to a Water Treatment Plant (WTP) .

A Reserve Ecological Water Requirement (EWR) was subtracted from the simulated actual river flow to determine available flow at Somkhele. Available water was further divided into normal and surplus flow, where normal flow (for each month of the year) is defined as flow that is exceeded in 70% of years and surplus flow is any excess above normal flow. A portion of surplus flow, especially flood peaks, in the Mfolozi River is abstracted into the pit lake storage system, in a manner that stabilises river flow and improves water availability to all downstream users. The proposed pit lake system acts as a balancing dam that abstracts only surplus flow above 17 ML/d (>2 m^3/s) and will only improve the hydrological situation during lows flows. During low flows the pit lake system will not abstract water from the river, but water will still be supplied to the WTP that serves the local community. The benefits of this balancing dam include meeting a portion of the (existing) Basic Human Need (BHN) requirements.

Measured river flow data of Mfolozi River from the Department of Water and Sanitation (DWS) gauging stations W2H005 and W2H006 (1960-2016) were obtained and proportionally extended for the downstream catchment, up to Somkhele, using simulated natural runoff records from Water Resources of South Africa, 2012 Study (WR2012 database) (Bailey and Pitman 2015).

Other input data obtained, included a sufficiently long daily rainfall record from the South African Weather Service (SAWS) for rainfall station 0339352_W (Kangela). Evaporation data were obtained from the WR2012 database (Bailey and Pitman 2015) and converted to lake evaporation. Parameters of a daily stochastic rainfall model were determined by using the methodology of Boughton (1999). Groundwater inflow into the pit-lake was simulated using methods described by Marinelli and Niccoli (2000). A topographical survey of the opencast mine pits was used to determine potential storage capacities of the pit lake system (Fig.2).

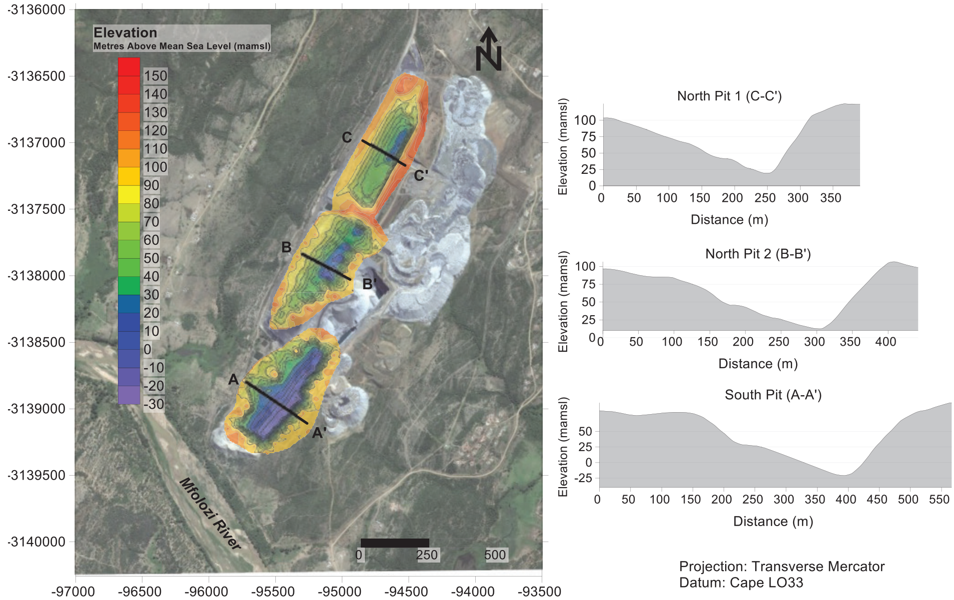


Figure 2 *Topography of opencast mine pits (with profiles).*

Water quality modelling estimated water quality in the various Somkhele opencast pits. A total of 25 rock samples from the existing opencast pits and borehole core samples were collected for geochemical testing. One (1) river sand sample was taken from the Mfolozi River bed. Test methods for the geochemical study are listed in Table 1.

A conceptual model was developed, which included typical processes that control acid-mine drainage generation. Geochemical modelling provided estimates of water quality for the pit lake system. Interaction between the mineral-, water- and the gas phases was modelled using the Geochemist's Workbench Professional®.

Water Resource Availability

Likely available flow at Somkhele for 96 years is displayed (Fig. 3) and was simulated at 600 million m^3/year with the Normal Wet Weather Flow (NWWF) equalling 670 mil-

Table 1 *Description of test methods.*

Test procedure	Expected outcome	Method
Acid-base accounting (ABA) (25 samples)	To indicate the long-term potential for AMD assuming all acid is generated by pyrite.	Modified Sobek (Lawrence and Wang 1997)
Net-acid generating (NAG) (25 samples)	To indicate the net potential for AMD after oxidation with hydrogen peroxide.	ASTM E1915-13 (2013)
X-ray diffraction (9 samples)	Minor to dominant minerals present in rocks.	-
X-ray fluorescence (8 samples)	Major oxides and trace elements present in rocks.	ASTM D4326-13 (2013)
Reagent water leach, 9 samples	To determine chemicals of concern that may potentially leach from samples.	Based on AS 4439.3 (1999) with additional ICP and UV-VIS analyses.
Peroxide Leach (3 samples)	To determine chemicals of concern that may potentially leach from the sample after oxidation by peroxide.	Based on ASTM E1915-13 (2013) with additional ICP and UV-VIS analyses on leachate.

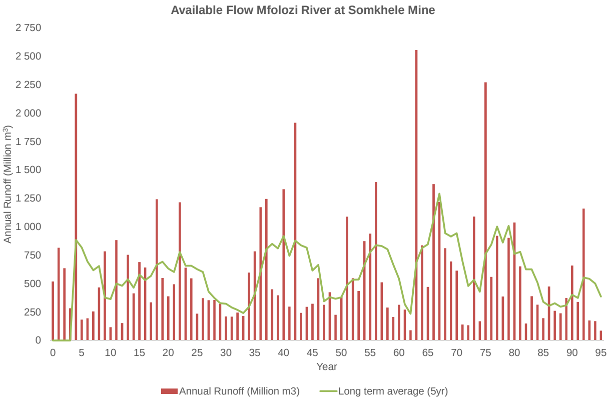


Figure 3 *Timeline of the 96-years flow availability of the Mfolozi River at Somkhele.*

lion m^3/year and the Normal Dry Weather Flow (NDWF) equalling 300 million m^3/year. Monthly available flow at the Mfolozi River after releasing the EWR is, on average, 424 million m^3/year.

Water levels simulated at 55 mamsl FSL for scenario 1 and scenario 2 in North Pit 1 and South Pit are presented (Fig. 4). It takes approximately 1 year to fill the pit lake system for both scenarios with no pumping to the WTP. Probabilities of water levels dropping below 40 mamsl is approximately 1:236 years for scenario 1 and 1:260 years for scenario 2. Low and very low risks of interruptions to 20 ML/d water supply to the WTP (water level <30 mamsl) were also simulated at FSL water levels of 50mamsl (1:166 years), 55mamsl (1:625 years) and 60 mamsl (>1:1 000 years).

A lower risk of exposing pit walls to oxidation suggests that pit water quality of the pits will be marginally better if water is pumped to North Pit 1 (scenario 2). Although water levels occasionally dropped below 40 mamsl, a sufficiently reliable supply of water (at 20 ML/d) to the WTP is achieved if target FSL water levels are maintained at 50, 55 and 60 mamsl.

Water Quality

Main lithologies are shale and sandstone and are mostly comprised of quartz and muscovite as major minerals with kaolinite, plagioclase and microcline as minor minerals. Small amounts of pyrite are present that can generate acid mine drainage, but carbonates present will provide some neutralising potential.

Water samples were collected from the sumps at the bottom of the operational opencast pits. The pH was neutral in all samples (>pH 7.7). EC was elevated above the South African National Standards (SANS) drinking water standard (>170 mS/m). Marginally to highly elevated anions included Na, SO_4, N, Cl, ammonia (as N) and F. Pb (0.016 mg/L) and Mn (1.59 mg/L) were erratically elevated in some samples. The river sand sample has a very low sulphide %S (below detection) and also have a very low neutralisation potential. It is expected that river sand samples have no potential to generate acidic drainage.

Due to large pumped volumes, the pit lake system will be a flow-through pit lake with no stratification taking place. A pit lake system designed with final pit water FSL between 40 and 60 mamsl, will leave most of the pit walls exposed to oxidation, especially in the North Pit 1 and North Pit 2. Run-off from the exposed pit walls/floor will have an increased TDS due to the oxidation of sulphides. In the long-term runoff into the pits will not acidify as more than 70% of waste rock has adequate neutralising potential. Neutralising minerals may only be partially exposed and run-off will initially drop to about pH 6 for about 20 years for the best case and about 40 years for the intermediate scenario. As a worst case, for wall rocks with a high pyrite content, the pH will drop to about pH 5 for about 10 years and then recover to pH 6 until year 70. In all cases the pH will recover over the long-term to >pH 8.

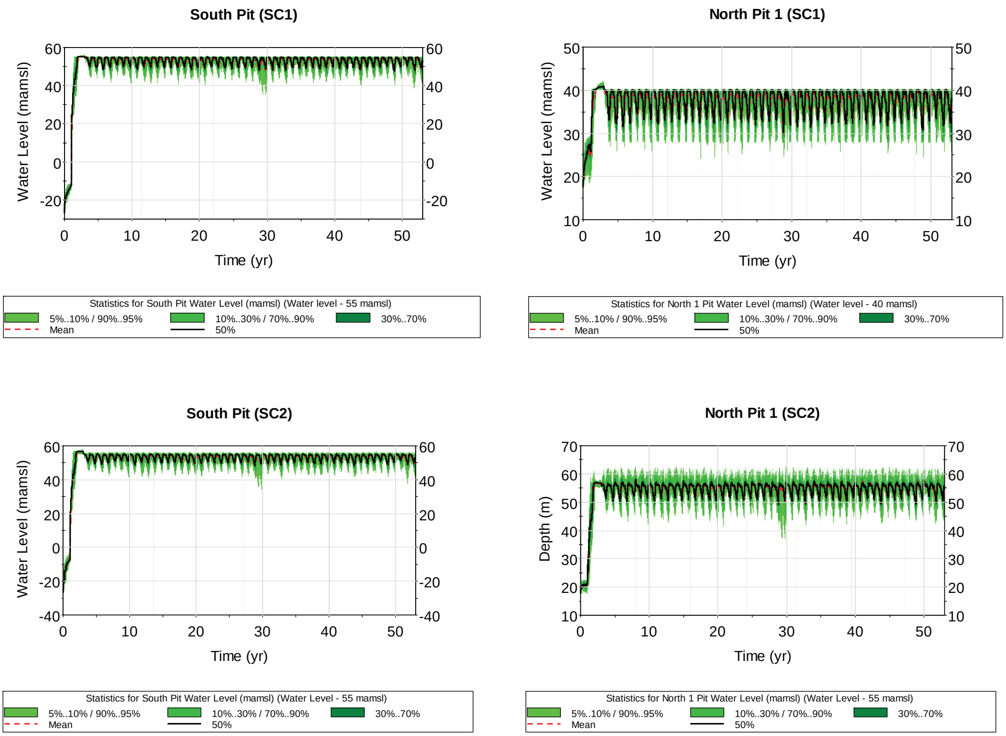
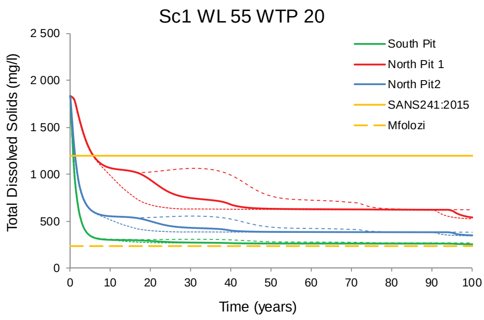


Figure 4 *Simulated pit lake water levels at 55 mamsl and pumping at 20 ML/d to the WTP for scenario 1 (top) and scenario 2 (bottom).*

Sulphate will become the dominant anion in pit runoff due to sulphide oxidation and secondary sulphate mineral dissolution. Sulphate initially reaches concentrations of up to 2 200 mg/L in run-off, which corresponds with currently observed water qualities in North Pit 2. As the secondary minerals in the wall rock deplete, sulphate concentrations in run-off will first reduce to 1 000 mg/L before decreasing further to about 350 mg/L.

Pit water will remain circum-neutral with pH above pH 6.5 and metal concentrations below 1 mg/L for scenario 1. A higher pump rate and a higher pit FSL have a positive effect on pit water quality. South Pit water will initially have a high TDS as pumped river water encounters the floor material (1 800 mg/L) (Fig. 5). Pit water quality will, however, improve significantly within 5 - 10 years owing to large volumes pumped from the river and reaches a pseudo-steady state after this time (with a TDS of 300-450 mg/L at 10 years and 260-330 mg/L at 100 years). After closure, North Pit 2 water quality will reach a pseudo-steady state within 30-40 years (TDS of 510-1000 mg/L at 10 years and 320-580 mg/L at 100 years). North Pit 1 water quality will reach a pseudo-steady state within 30-40 years (with a TDS of 940-1800 mg/L at 10 years and 470-870 mg/L at 100 years).

Water quality effects are less pronounced in scenario 2 (Fig. 5), because of inflow of river water in North Pit 1 and high resultant flow between the pits dominates the pit water quality. North Pit 1 water quality will improve significantly within 1 - 3 years (due to the large volume of river water pumped towards the pit) and the TDS will reach a pseudo-steady state after this time (≈260-340 mg/L at 10 years and ≈240-280 mg/L at 100 years). The North Pit 2 water quality will improve significantly within 1 - 3 years (due to the large inflow of relatively clean water from North Pit 1) and the TDS will reach a pseudo-steady state after this time (≈280-420 mg/L at 10 years and ≈250-310 mg/L at 100



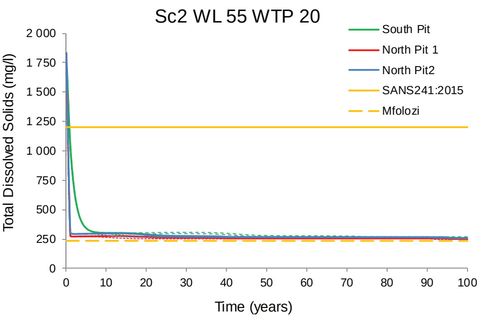


***Figure 5** Change in pit water quality over model time at 55 mamsl FSL for scenario 1 (left) and scenario 2 (right) for a 20ML WTP. The solid line presents the intermediate case and the upper and lower dashed lines the worst and best case.*

years). South Pit water quality will improve significantly within 5 - 10 years (due to the large inflow of relatively clean water from North Pit 2) and the TDS will reach a pseudo-steady state after this time (≈290-460 mg/L at 10 years and ≈250-340 mg/L at 100 years). South Pit will have a slightly higher TDS than the other pits because it is situated furthest downgradient.

Summary Conclusion

This investigation indicated that water supplied from the pit lake system will be a more reliable alternative than supplying water directly form the Mfolozi River. The local river cannot reliably supply drinking water directly to the WTP, whereas a pit-lake system can function as a balancing dam of up to 11.7 Mm^3 (at 55mamsl FSL), which provides water during drought periods. Water quality will still be within the drinking water limits based on worst-case assumption of the impact of the pit walls on water quality for all scenarios. The nearby WTP could be upgraded to meet current shortfalls in supply to meet local domestic water demands.

Ongoing investigation include the selection of an abstraction site and selection need to be made based on accessibility to the site, river bed stability and confirmation on whether expected pump rates could be obtained. Additional pump testing on the Mfolozi River bed is recommended in order to confirm whether the water quality in the river bed will not deteriorate over time. Mfolozi River flow and the pit water levels should be monitored on a monthly basis. Further test work should also include kinetic leach testing on selected wall rocks in order to better estimate the expected impact of the material on drainage water quality. Also the geochemical model should be updated over the life of the project in order to calibrate and validate its results with the actual site conditions.

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