Integrated and Sustainable Mine Water Management Solution for Witwatersrand Gold Fields

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Abstract

The flooding of the Witwatersrand gold basins is one of the critical issues around mine water management in South Africa. Previously, a high level assessment by an Inter-Ministerial Committee, advised pumping and treating of mine water among others. However, this option is expensive and drain valuable resources. Research undertaken by the Council for Geoscience on behalf of Department of Mineral Resources and Energy suggests that environmental critical limits can be relaxed, subject to further investigations. In addition to adjusting Environmental critical limits, complementary management options such as mine water discharge adits, ingress control measures and *in-situ* treatment can be integrated.

Keywords: Witwatersrand gold fields, Mine water management, Environmental critical limits.

Introduction

A high level assessment by an Inter-Ministerial Committee (IMC), advised by a Team of Experts on Acid Mine Drainage in 2011 identified risks related to mine flooding and rising water levels, including contamination of shallow groundwater, geotechnical, seismic and ecological impacts, regional impacts on major rivers systems and localised flooding in low-lying areas in Witwatersrand Goldfields. Therefore, the IMC Team of Experts on AMD, recommended that the water level in the three original mining basins (Eastern, Central and Western) should be maintained at or below certain environmental critical levels (ECLs) – the site-specific highest water level within a mine void where no mining influenced water flows out of the mine workings into the surrounding groundwater or surface water systems – through:

- Pumping and treating of mine water in all the three basins; and
- Prevention of surface water ingress from entering into the mine voids.

Consequently, as a short term intervention, pump stations feeding High Density Sludge (HDS) treatment plants were established in all the three basins by the Department of Water and Sanitation and started pumping and treating mine water. Furthermore, the Council for Geoscience (CGS) and Department of Mineral Resources and Energy (DMRE) are implementing a programme to identify surface ingress points and construct measures to reduce the ingress of water to the mine voids. This programme aims to reduce the volume of water to be pumped and treated, reduce the seasonal variability in inflows to the mine voids and to keep clean water in surface streams.

The cost of pumping and treating mine water in perpetuity puts pressure on the government fiscus. Moreover, the ECLs recommended in 2011 were conservative and based on the information available at that time. Subsequently, research undertaken by the CGS on behalf of DMRE has recommended that ECLs can be relaxed in a phased approach without compromising on the status of the environment by ensuring adequate monitoring systems are put in place, and water levels are controlled in response to the results of monitoring. In addition to adjusting ECLs, complementary mine water management options such as discharge adits, ingress control measures and *in-situ* treatment can be integrated into a broader strategy to manage the mine water challenges in Witwatersrand basin before pumping and treating of mine water can be terminated. With this background, we have identified a potential less invasive integrated and sustainable mine water management system for the Witwatersrand gold fields.

Conceptualisation of an integrated solution

The solution presented in this article was conceptualised based on:

- the monitoring data received from Department of Water and Sanitation (DWS) on mine water levels and water quality in the mining basins,;
- Extensive experience and improved knowledge on the Witwatersrand mine water behavioural patterns,
- A preliminary concept of discharge adits;
- Results from the surface water ingress control measures into the mine voids; and
- Data collected during a period when lime-neutralised tailings were disposed of in the western basin and laboratory trials using various alkaline materials as *in-situ* neutralising agents.

In-Situ water treatment

Between 2016 and 2018, a mining company operating in the Western Basin disposed of limed tailings into an open pit connected directly to the underground mine workings. During this period, it was observed that the quality of water collected at sampling points in the mine void and pumped from the void improved. After the cessation of operations, the water quality returned to levels similar to those which had existed before the commencement of this operation. While this was not a planned or intended consequence of the tailings disposal, the potential for *in-situ* neutralisation of mine water in the Witwatersrand was noted.

South Africa is a developing country and a massive infrastructure development planning is underway to stimulate the economy. Therefore, it is expected that number of aged buildings will require reconstruction and as a result, there will be a substantial increase in the generation of waste concrete in the country. This requires a fundamental shift in the strategy on how this waste stream will be managed. Considering, the alkaline properties of waste concrete and challenges around mine water management in South Africa, waste concrete was identified as a potential *in-situ* mine water neutralising agent.

Laboratory trials were conducted to understand the potential of *in-situ* neutralisation of water in the mine voids, using waste concrete as an *in-situ* neutralising agent. As an initial step, an alkaline mixture at a waste concrete: tap water ratio of 2:1 was prepared. This was introduced into a reaction container (without agitation) to make an alkaline mixture: mine water slurry at a ratio of 1:13, to mimic introduction of alkaline material into the mine voids. The pH and EC of the samples were measured over a period of 28 days, and a sample of the water was analysed for metal and anion concentrations at the end of the 28 day period.

A rapid increase in pH- from 5.6 to 6.6 was observed within one minute upon introduction of waste concrete slurry into the raw mine water. Subsequently, the pH of the mixture further increased to 7.83 on day seven and then stabilised and remained constant until the last day of monitoring (28 days). The results generally suggested that the neutralisation of the mine water improved with contact time. Likewise, the electrical conductivity (EC) readings decreased from 4.96 mS/cm to 3.52 mS/cm within one minute upon introduction of waste concrete slurry into the raw mine water. On day seven, the EC had reached 3.50 mS/cm with a final value of 3.84 mS/cm on day 28.

After 28 days of *in-situ* treatment, the sulfate concentrations in the mine water reduced from 3,563 mg/L to 2,479 mg/L, which is similar to the final sulfate concentrations in the treated mine water discharged from the HDS plant which treats this water. Ca from the waste concrete was

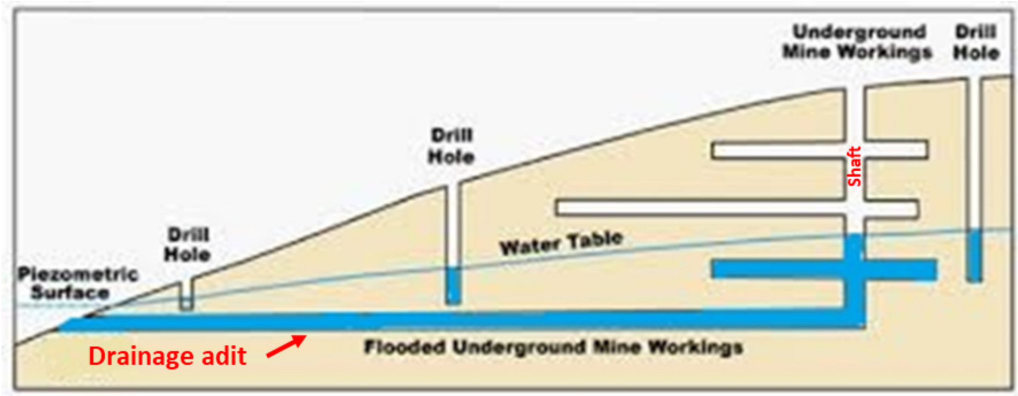

Figure 1. Schematic design of drainage adit (Source: adapted from Bourgeot et al., 2016).

leached into the reaction mixture with final concentrations above the initial levels in the raw mine water. A notable percentage of Fe and Mn levels were also observed to be removed in the final treated mine water.

Discharge Adits

The use of discharge adits to drain flooded mine voids in the Witwatersrand goldfields was also considered. Discharge adits are useful in controlling flooding in underground mines, owing to their design which takes advantage of gravity to allow for the free flow of water from mines. It was recommended that in areas where the topography allows an adit to be constructed to intercept the mine workings at an acceptable water level, the construction of discharge adits in the Witwatersrand goldfields could present a cheaper option compared to the current scenario of pumping large volumes of water. Furthermore, discharge adits will not only

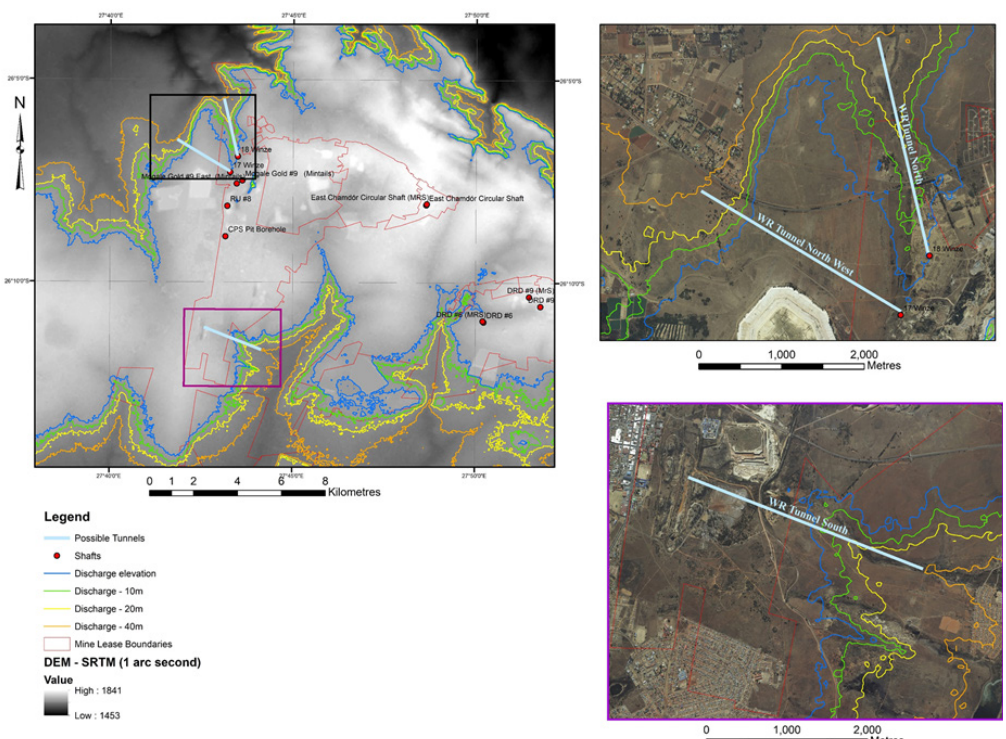

Figure 2. Potential discharge adit sites in the West Rand Goldfield.

offer a solution to flooding control but may also act as an excellent drainage pathway for treated water after *in situ* treatment process, thus helping in reducing the overall operational costs of mine water management. Figure 1 is a schematic design of a drainage adit (Bourgeot et al., 2016).

Studies into the construction of adits/ tunnels, for controlled water discharge in parts of the Witwatersrand goldfields, have previously been conducted (Arnold et al., 2005). The studies resulted in the identification of potential sites for the construction of discharge adits, as well as detailed designs for the proposed adits. Potential sites have been identified in all the three basins of wits basin. Figure 2 is a potential discharge adit site based on the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) in the West Rand goldfield.

Ingress Control

Flow of water into the mines of the Witwatersrand has been an issue since the early days of mining. Scott (1995) compiled anecdotal evidence and historical records detailing the inflow of water into mines, as well as early measures undertaken to prevent the ingress of water into the underground workings. A programme, supported by the Department of Mineral Resources and Energy has been identifying and constructing engineering measures to reduce the ingress of surface water into the underground workings (Barradas et al., 1996; Coetzee et al., 2021; Palmer et al., 2006; van Biljon & Walker, 2001). The underlying logic of ingress control is that preventing the flow of surface water into the underground mine workings keeps that volume of water on the surface in a relatively unpolluted state. If the water flows through the mine workings, it will become contaminated by interaction with sulfide minerals and their soluble oxidation products. This water will then either discharge to the surface, creating extensive downstream pollution (Hobbs & Cobbing, 2007), or require pumping from the underground workings and treatment before reuse or discharge to the environment. Ingress control is therefore seen as a lower cost and energy efficient (Ntholi & Madzivire, 2018) water management option, as it avoids the cost of pumping and water treatment.

Examination of the pumping records from the existing pump and treat plants in the Witwatersrand shows a substantial seasonal difference between inflows in the region's wet summers and dry winters, as well as short-term variations caused by intense rainfall events. As long as water management relies on pumping, this can be accommodated using the mine voids to buffer volumes. A gravity-driven discharge system will not be able to buffer the effects of variable ingress volumes. As ingress control measures target surface water, where flows are strongly influenced by seasonal cycles and individual rainfall events, the implementation of ingress control will tend to reduce variability of flow from the mine workings.

Ingress control measures which have been identified include:

- The construction of canals crossing the zones of shallow undermining, to prevent seepage and direct flow into workings;
- The sealing of mining, subsidence and localised geological structures which link surface water bodies with the underground workings; and
- Diversion of surface water away from undermined zones to prevent seepage or direct inflow.

A number of measures of all three types have been successfully implemented in the Witwatersrand Goldfields. Ingress volumes calculated using water level and pumped volume data from the Eastern Basin Plant have shown that well-planned ingress control measures can result in substantial cost savings for water management.

Revision of ECLs

The 2010 report to the Inter-Ministerial Committee on Acid Mine Drainage (Coetzee et al., 2010) defined environmental critical levels (ECLs) as the highest level to which water can be allowed to rise in the underground workings of the Witwatersrand without posing a risk to the surrounding environment, including groundwater resources. ECLs were recommended for the Western, Central and Eastern Basins, based on the information available at the time. A lack of specific information necessitated a number of conservative assumptions, resulting in ECLs which, while safe, included a large safety margin. As more information, particularly from targeted monitoring programmes becomes available, it is expected that these ECLs can be relaxed, with two benefits:

- Pumping from shallower depths will be cheaper; and
- Allowing the water levels to rise in the mine voids will exclude oxygen from the upper part of the workings, decreasing the generation of new acidity by the oxidation of sulfides. This effect will be limited as substantial workings are known to exist above the level of the lowest lying shafts that would define the eventual water level if no pumping took place.

Even with the elevated water levels in the mine workings, following two successive La Niña events, leading to higher than usual rainfall, compounded by lower-than-expected volumes pumped, no groundwater contamination has been reported in areas likely to be affected by the Central and Eastern Basins. In the Western Basin, the workings are almost completely flooded, resulting in localised subsurface flow to an adjacent karst system and some seepage of contaminated water to the surface. It is therefore recommended that the ECLs in all three basins can be adjusted to shallower depths, on the condition that current monitoring systems are maintained and extended to provide early warning of any groundwater contamination.

Discussion

Combining these elements of water management, a hypothetical long-term water management strategy is developed, aiming to achieve the key objectives highlighted in the Team of Experts' report to the Inter-Ministerial Committee in 2010. This strategy aims to reduce the long-term cost of mine water management, align with the United Nations sustainable development goals and (United Nations, 2018) and produce a solution which prioritises resilience. The key elements of this strategy are presented in Table 1.

This complements and reduces the burden on the short to medium term mine water management strategy by reducing the volumes and improving the quality of mine water to be treated and perhaps provides an alternate solution for long term management of mine water, which relies on desalination (Department of Water Affairs, 2012) with the attendant high costs and energy requirements., , However, the feasibility of this approach still requires additional study, to determine optimal ECLs for the three basins, and fully investigate the potential of *in-situ* treatment and possible requirements for post-discharge measures to improve water quality. A number of ingress control projects have been successfully implemented and have been demonstrated to reduce the volume of water flowing into the underground workings.

Table 1 *Proposed long-term sustainable water management strategy*

Water management objective	Proposed management option	Enabling factors
Discharge water at an environmentally acceptable quality.	Implement *in-situ* treatment before final discharge to the environment.	Reduction in discharge volume and seasonal variability in volume to be achieved via ingress control.
Maintain the water level at an environmentally acceptable level	Develop discharge adits at appropriate elevations.	Optimisation of the ECLs will allow shorter discharge adits to be used, reducing overall cost.
Keep clean water clean	Ingress control to minimise flow through the mine void, resulting in water contamination	

Conclusions

A conceptualised alternative sustainable solution for mine water management in Witwatersrand mining basins, based on the integration of less aggressive technologies is proposed. The different mine water management elements such as rising ECLs, *in-situ* treatment, discharge adits and ingress control can be practical in long term and should be studied further, and can be combined with other water management options.

Acknowledgements

The research team would like to express their gratitude to DMRE for providing funding to the research.

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