Flooding of the underground mine workings of the old Witwatersrand gold/uranium mining areas: acid mine drainage generation and long term options for water quality management

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Abstract. The underground workings in the older parts of the Witwatersrand Gold Fields of South Africa have been abandoned and allowed to flood. Pyrite in the ore and host rock leads to the generation of acid mine drainage in the flooding underground workings as well as in surface residue deposits. The difference in topographic elevation across these goldfields creates a driving hydrostatic head which has caused the discharge of acid mine drainage in the West Rand Gold Field and threatens to cause similar problems in the Central and East Rand. Laboratory simulations and simple models have been used to try to understand the hydraulic and chemical dynamics of the flooding mines with the aim of optimising solutions to this problem in the medium- to long-term.

Introduction

South Africa's Witwatersrand Gold Fields extend along an arc of more than 300km from the Free State in the South West, to the Evander area in the North East, passing through the City of Johannesburg. Gold and co-occurring uranium are extracted from narrow dipping pyritic conglomerate bands, extending to depths of more than 4km in places. After the discovery of Gold in 1886 in what would soon become the City of Johannesburg, mining commenced in the Central, West and East Rand Gold Fields, with surface operations soon giving way to deeper underground operations.

The continuous nature of the ore bodies has led to the excavation of large complexes of hydraulically interconnected underground mine workings. In the Johannesburg area, 3 large gold fields – the East Rand, the Central Rand and the West Rand developed (Figure 1), separated by geological structures resulting a discontinuities in the ore bodies and hence breaks in the hydraulic interconnection of the mines. Deep underground mining ceased in these three gold fields between 1998 and 2011 and the workings were allowed to flood. Gold and, in some cases uranium, are still extracted extracted from mines in other gold fields, accessing the Witwatersrand Supergroup ores to the east, west and southwest of Johannesburg, along a strike length of approximately 300km.

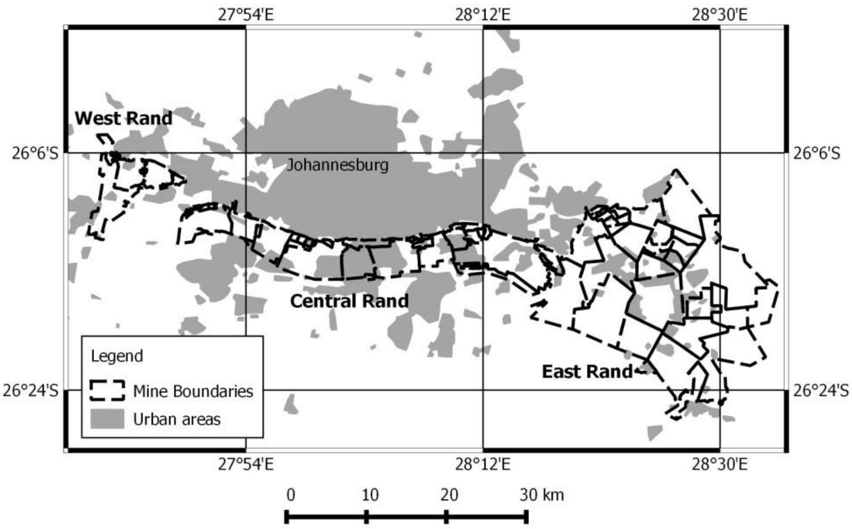

Fig 1. Location of the gold fields in the vicinity of Johannesburg

Anecdotal reports of acid water in the Witwatersrand mines can be traced back for decades (Hocking 1986). During mining operations, water was pumped from the voids and neutralised before being discharged to surface streams. After the cessation of underground operations in the West Rand in 1998, the underground workings were allowed to flood, with water first decanting to surface streams in 2002 (Hobbs and Cobbing 2007). In 2010, an Inter-Ministerial Committee was formed to address this situation and a technical proposal adopted to manage AMD in the three affected gold fields by pumping and treatment (Ramontja et al. 2011).

Development of solutions to high-priority mining areas

The solutions proposed for the three affected gold fields are based on similar principles. The water level should be maintained at or below an Environmental Critical Level (ECL), defined to be the minimum depth which will ensure that no water decants to surface or flows into surrounding aquifers. In the case of the West Rand, where AMD has already discharged to surface, this will require pumping to lower the water level, while in the Central Rand and East Rand, pumps are needed to maintain the water level and stop it from rising. The proposed ECLs have been established using conservative assumptions, and may be brought closer to the surface when control over the water level has been established by pumping.

It is anticipated that the water quality will be poor, with the West and Central Rand Gold Fields having produced acidic water in the past, while the East Rand is expected to produce a circumneutral water. All of these will require treatment. Regional considerations make the desalination and re-use of the mine water the most environmentally attractive option (Department of Water Affairs and Forestry 2009). The options for the different Gold Fields are summarised in Table 1.

Table 1. Information required for the design and implementation of the short-term solution for acid mine drainage in the Witwatersrand.

Information required	West Rand	Central Rand	East Rand
Environmental Critical Level	Maximum depth to ECL well constrained due to good conceptual hydrogeological model.	ECL poorly defined using a simple conceptual understanding of groundwater levels.	ECL conservatively defined based on possible interactions with near-surface dolomitic aquifer.
Required pumping rate	Difficult to determine due to a lack of historical pumping data and poor flow measurements under decant conditions	Based on reported pumping rates.	Based on reported pumping rates.
Expected water quality	Based on intensive monitoring of decant and decant affected systems over several years.	Based on modelled and reported water quality.	Based on measurements on pumped water (circumneutral)

Anticipated water quality

Topographic controls over the level of flooding in the Witwatersrand mine voids

The surface topography of the Witwatersrand undulates, with the elevation along the trace of the Main Reef varying between around 1650m and 1750m above mean sea level in the Central Rand and 1700m and 1800m in the West Rand. The surface discharge points for both of these mine voids is a few tens of metres below the lowest point on the reef outcrop at or close to lower lying shafts accessing the void. In both cases, the environmental critical level has been determined to be around 150m below this (Ramontja et al. 2011). As a result, at the topographic highs within each gold field, as much as 300m of vertical extent of the mine void will not be flooded, exposing sulphide-rich ore and host rock to air, while water entering this zone will flow though the underground workings towards the flooded zone below this level. Even if the voids were allowed to flood completely and discharge to surface, underground workings with a vertical extent of up to 150m would remain open.

Laboratory simulation of the saturated and unsaturated zones in the underground mine voids

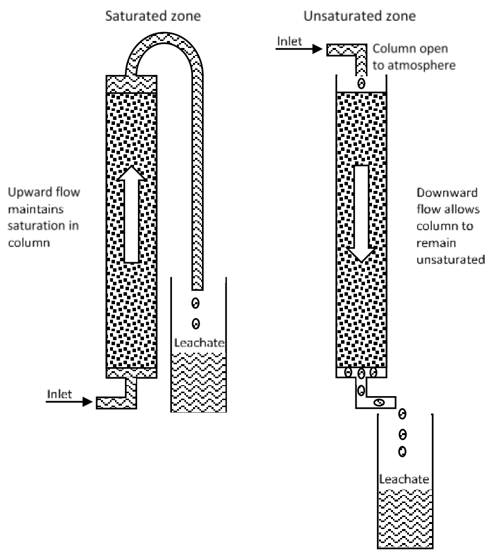

Fig.2. Column setup for the comparison of AMD generation in the saturated and unsaturated zones of the underground mine voids of the Witwatersrand.

The impact of this unsaturated surface zone in the underground workings has been investigated experimentally, using different column configurations, as illustrated in Figure 2. A sample of pyritic conglomerate was collected from an abandoned open cast operation in the West Rand Gold Field. The sample was crushed and a <4mm fraction collected. Two subsamples with masses of approximately 1.3kg each were placed in columns 5cm in diameter and 40cm long, and inoculated with acid mine water collected from a shaft in the vicinity of the sampling site. One column was configured for upward flow, ensuring complete saturation with water and the other left open at the top with water percolating downwards through it. The water flow rate in both columns was adjusted to allow a flow of approximately 1L/kg every three weeks. At the time of writing, this experiment had been running for 71 weeks, giving a cumulative liquid to solid ratio of approximately 23L/kg.

pH and electrical conductivity values for the two column experiments are presented on Figures 3 and 4 respectively. The unsaturated column shows a sharp deterioration in water quality at a liquid to solid ratio of around 8L/kg, most likely indicating the consumption of all available buffer capacity in the sample. In the saturated column, water quality improves sharply soon after the start of the measurement period, representing the washout of already oxidised material and any residual acidic water remaining from the inoculation of the columns.

The implication for long-term water management is that flooding to higher levels would reduce the oxygen availability in the flow path from the surface and near-surface ingress of water to the underground workings, potentially resulting in better quality water reporting at the pump stations, with a consequent reduction in treatment cost. The cost of pumping from shallower depths would also reduce the total cost of water management, while the possibility of a gravity-driven decant tunnel may become technically and economically feasible.

The implications of an upward adjustment of the current determinations of the environmental critical levels would need to be fully assessed, particularly where this could have a negative effect on groundwater quality. It must be remembered that the currently proposed environmental critical levels have been determined conservatively, based on limited information. The current short-term initiative to pump and treat water to regain the pre-flooding status quo will provide valuable information with regard to the hydrodynamics of the underground workings and possible interactions with shallow groundwater.

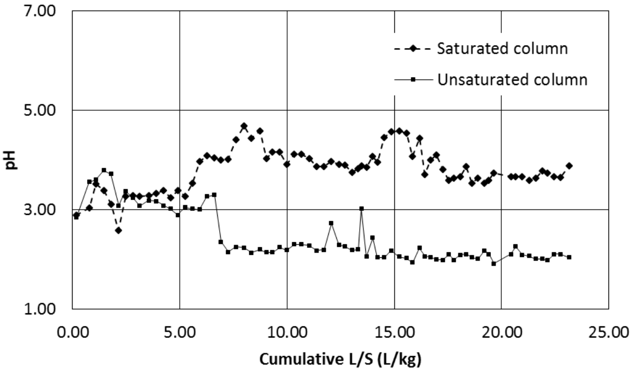

Fig.3. pH values recorded for the saturated and unsaturated columns used to simulate water flow through the saturated and unsaturated zones in the Witwatersrand mine voids.

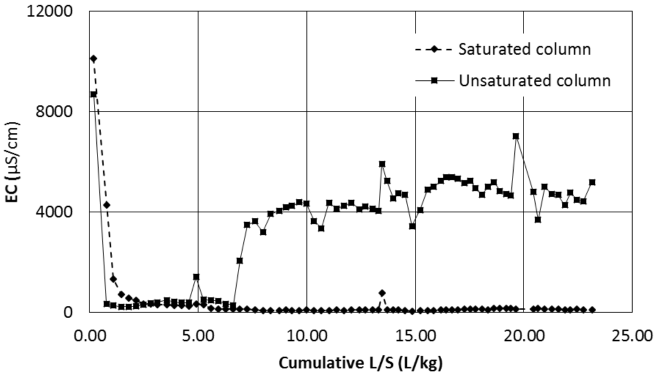

Fig.4. Electrical conductivity values recorded for the saturated and unsaturated columns used to simulate water flow through the saturated and unsaturated zones in the Witwatersrand mine voids.

Anticipated water volume

For planning of the required pump and treat facilities in the Witwatersrand it was essential to predict the ultimate volume of water which would require treatment. At the times that mines closed, no reliable measurements of water volume were available, complicating the selection of pumps and the design of treatment facilities. In the Central- and East Rand Gold Fields, summaries of historical pumping data could be used, presented by Scott (1995), based on historical data from earlier periods when multiple mines were operating and pumping. These values were used as a basis for design.

Prediction of the required pumping rate for the West Rand

In the West Rand Gold Field, no reliable and comprehensive record of historical pumping data could be identified. Initial planning after the flooding of the underground workings and discharge to surface in 2002 was based on a modeled discharge rate of between 7 and 12ML/d (pers comm. M van Biljon), but designs based on this proved inadequate for the volumes of water discharging.

Data collected by the mines in the area between January 2010 and June 2011 show a reported discharge (pumped or decanted to surface) volume between 12.5 and 67.2ML/d, with strong seasonal variation. Furthermore, the water level was monitored throughout the flooding of the underground mine void (pers comm. M van Biljon). This provides sufficient data to estimate the recharge to the mine void and, in combination with the rate of rise during mine flooding, can be used to estimate the volume of the mine void for any specified depth interval. It should be noted that the data available covered only slightly more than a single hydrological year, making a robust prediction, incorporating year-to-year variability in discharge rate impossible. The quality of the measured flow data could also not be verified.

Despite the inherent uncertainty in the available data, a simple model was constructed (Coetzee, 2011) using the basic assumption that, recharge to the underground workings is equal to the discharge from the underground workings, when flooded to surface decant level. A specified pumping volume could then be subtracted from this recharge value and the difference be used to predict the change in water level, based on the water level curve measured during flooding of the underground workings. Using this model it was recommended that a pumping volume of 40ML/d would dewater the underground workings and lower the water level to the ECL within a reasonable period of time.

Pumping throughout the 2013 dry season lowered the water level in the mine void from decant level by more than 1 metre. Unfortunately, technical problems with the pumps, together with above average rainfall recorded in early 2014 caused the discharge of AMD to the surface to start again in March 2014 (Kolver, 2014).

Conclusions

The acknowledgement of acid mine drainage as a problem by the South African government in 2010 facilitated the development and start of implementation of practical solutions to the problem in areas where deep underground mining has ceased and the underground voids have been allowed to flood. Because of insufficient pre-closure planning, very little rigorous prediction of the rate and consequences of flooding was done and the flooding process was not managed.

Limited data were available for the prediction of water volumes and flow rates and the consequences of flooding, creating a requirement for the proposal of solutions based on conservative conceptual models of the flooding process and AMD generation. In some cases, it will only be possible to properly validate these models during the flooding and solution implementation processes.

Laboratory simulations have indicated that in mining areas such as the Central- and West Rand Gold Fields, where the discharge level is lower in elevation than a large portion of the underground workings, AMD generation is likely to continue due to the flow of water through air-filled voids, while it may be expected to be limited in the lower levels which are fully flooded.

Estimates of water volume have been difficult due to a lack of reliable historical data on pumping volumes. It is nevertheless possible to predict appropriate pumping volumes using limited historical data.

These results underline the importance of comprehensive planning for long-term water management before the closure of complex underground mining operations with the potential to generate acid mine drainage. In areas where multiple mines are interconnected, such as South Africa's Witwatersrand Gold Fields, closure planning must be undertaken at a regional scale as well as the scale of individual mines.

References

Coetzee, H. (2011). A flooding and pumping model for the Western Basin of the Witwatersrand Gold Fields, based on empirical data. Council for Geoscience Report No. 2011-0176, Pretoria, Council for Geoscience: 10pp.

Department of Water Affairs and Forestry (2009). Vaal River System: Large bulk water supply reconciliation strategy: second stage reconciliation strategy (March 2009). Report Number P RSA C000/00/4406/08, Pretoria, Department of Water Affairs and Forestry**:** 130pp.

Hobbs, P. J. and Cobbing, J. E. (2007). A hydrogeological assessment of acid mine drainage impacts in the West Rand Basin, Gauteng Province. CSIR/NRE/WR/ER/2007/0097/C, Pretoria, CSIR/THRIP: 59pp.

Hocking, A. (1986). Randfontein Estates: The first hundred years. Bethulie, Hollards.

Kolver, L. (2014). Govt lauded for AMD paradigm shift, but complexity not fully grasped. Mining Weekly, 18 April 2014. Creamer Media.

Ramontja, T., Coetzee, H., Hobbs, P. J., Burgess, J. E., Thomas, A., Keet, M., Yibas, B., van Tonder, D., Netili, F., Rust, U. A., Wade, P. and Maree, J. (2011). Mine Water Management in the Witwatersrand Gold Fields With Special Emphasis on Acid Mine Drainage Pretoria, Inter-Ministerial-Committee on Acid Mine Drainage. Report of the Team of Experts for the Inter-Ministerial Committee on Acid Mine Drainage**:** 146.

Scott, R. (1995). Flooding of Central and East Rand Gold Mines; An investigation into controls over the inflow rate, water quality and the predicted impacts of flooded mines, Pretoria, Water Research Commission: 238pp.