Flooding of the underground mine workings of the Witwatersrand Gold Fields

Henk Coetzee

Council for Geoscience, Private Bag X112, Pretoria, 0001, South Africa, henkc@geoscience.org.za

Abstract South Africa's Witwatersrand Gold Field has produced almost 40 % of all the gold ever extracted, as well as being a significant source of uranium. The gold occurs in pyritic conglomerates located along the "Golden Arc" centred on the city of Johannesburg. Mining has led to the excavation of a series of large interconnected underground voids. In the oldest mining areas, underground mining has all but ceased and the workings have been allowed to flood. Since 2010, concerted efforts have been made to address the existing and potential impacts of AMD in this area.

Keywords Witwatersrand, acid mine drainage, legacies

Introduction

Gold occurs in the Witwatersrand Gold Fields in a number of conglomerate layers (locally known as reefs) within a large Archaean sedimentary basin. Resistant quartzite layers within this sedimentary pile define the ridge which gives the area its name, the "White Water Ridge". This ridge forms a continental water divide. Water falling to the north of the ridge flows north towards the Limpopo River, eventually flowing east to the Indian Ocean, while water falling south of the ridge flows south and west into the Vaal River and eventually to the Atlantic Ocean. The mineralised layers contain significant amounts of pyrite and elevated concentrations of uranium, which has been produced as a by-product of gold mining in some areas. Gold was discovered in Johannesburg in 1886, with a significant industry developing soon after. The initial gold discovery occurred in the Central Rand (largely located in the city of Johannesburg), with subsequent discoveries being made in the West Rand and East Rand (Fig. 1). Later discoveries were made in a number of areas where the Witwatersrand reefs are largely covered by younger rocks, with mining eventually developing along more than 300 km of strike length. In the years following the 2nd World War, significant amounts of uranium were also produced. Mines are developed within a number of more or less contiguous mining complexes, which define individual gold fields. Because of its location on the water divide, Johannesburg and the surrounding urban and industrialised areas are not located close to a significant water source, requiring water to be pumped to the city from the Vaal Dam some tens of kilometeres to the south.

Early mining was limited to the surface outcrops but it was soon realised that these were the surface expression of extensive southward-dipping sedimentary layers extending to great depths. The high costs of underground mining led to the consolidation of mines into large units which were interconnected at depth across the major goldfields. This interconnection allows water to flow relatively freely between the underground workings of mines within each of the gold fields (Pulles *et al.* 2005). Following the cessation of underground operations in many of the mines, water flowing into large areas of underground workings needed to be pumped by fewer and fewer operators. This became extremely costly for the remaining mines. Even-

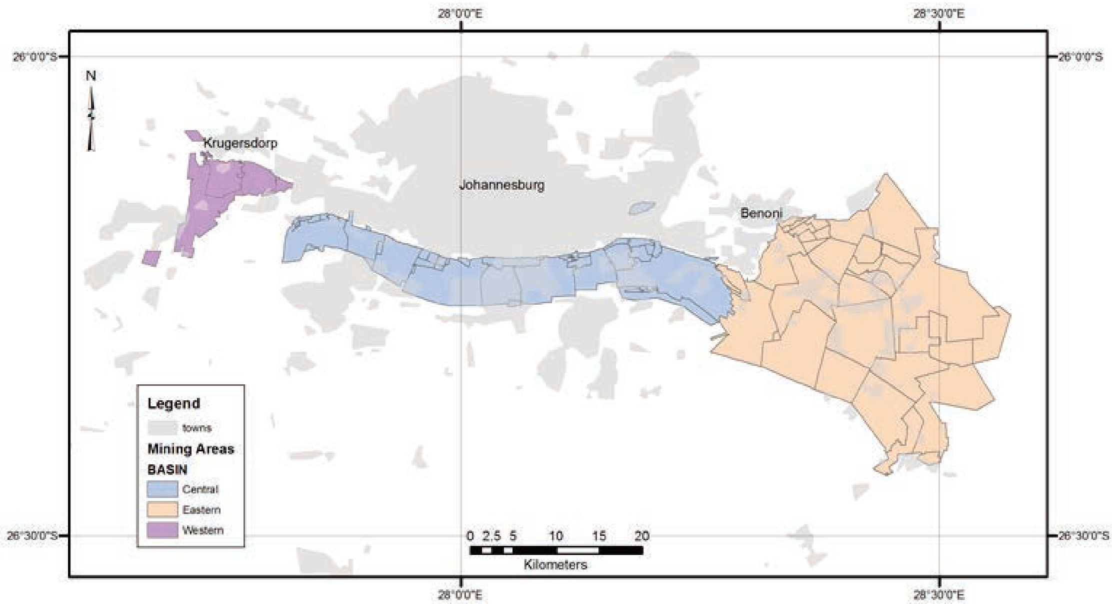

Fig. 1 *Location of the Western, Central and Eastern mining basins of the Witwatersrand Gold Field, relative to the populated urban areas of Johannesburg and its surrounds (Ramontja et al. 2011).*

tually these mines also ceased operations, stopped pumping and the interconnected mine voids began to flood.

Pumping ceased in the West Rand Gold Field in 1998. At the time, the mining company involved commissioned the development of a flooding model which predicted that water would decant from the underground workings to the surface in 2002. This prediction proved correct (Coetzee *et al.* 2005), with polluted water discharging into a stream to the north of the water divide (Fig. 2). Water polluted by Witwatersrand mining activities typically displays low pH, high TDS, high SO_4 (Ramontja *et al.* 2011) and may be contaminated with a range of metals, with uranium being among the contaminants of greatest environmental concern (Coetzee *et al.* 2006). Despite reports of acidity in this water as far back as the 1950s (Hocking 1986) no plans were put in place by either the mine owners or government agencies and the decanting water entered local aquifers and surface streams with serious negative effects (Hobbs and Cobbing 2007; Hobbs 2013).

In the Central and East Rand Gold Fields, single pump stations maintained the water at a level which permitted mining to continue, both of these discharging to the south of the water divide. These were operated by the last mines to operate within these areas and partially subsidised by the State in an effort to maintain gold production in these areas. Eventually these two operations also ceased pumping due to a fatal underground accident in the Central Rand in 2008 (Ramontja *et al.* 2011) and the liquidation of the last company pumping water in the East Rand in early 2011. The underground workings in these gold fields then also started to flood (Janse van Vuuren 2011).

Legislative environment

Mine closure and mine water management in South Africa are governed largely by the Mineral and Petroleum Resources Development Act (Act of No. 28 of 2002) and the National Water Act (Act No. 36 of 1998). These acts govern all aspects of the licensing, operation, environmental management and closure of mining operations as well as providing specific conditions on the use

***Fig. 2** Acid mine drainage discharging from an abandoned mine shaft in the West Rand Gold Field.*

and pollution of water. However historical legislation which governed mining was not as comprehensive, particularly with respect to environmental management and closure (Coetzee *et al.* 2008; van Tonder *et al.* 2008).

Regional considerations

A key concern is the discharge of acid mine drainage into rivers flowing to the south of the water divide. Before the cessation of pumping by the mines, water was neutralised and discharged to local streams which flowed south towards the Vaal River. Although this discharge entered the Vaal downstream of the point of abstraction for Johannesburg, it was known to affect downstream water quality. Historically this water quality impact has been mitigated with discharges of clean water from dams upstream of this discharge point. However this will not be sustainable in the long term, particularly as water is already transferred into the Vaal River System from other areas via expensive inter-basin transfer schemes (Department of Water Affairs and Forestry 2009).

Desalination of point sources of mine water is seen as an important component in the management of water quality at a regional level. This water will then be suitable for augmentation of local water supplies for domestic, agricultural or industrial use. However the often unseen benefit of removing the polluted water from river systems is that it makes water that would otherwise be required to dilute downstream saline discharges available for use, reducing the need for expensive augmentation schemes (Department of Water Affairs and Forestry 2009).

Proposal of solutions

The flooding of these mines and the risks posed by AMD discharges were identified before the flooding of mines commenced (Scott 1995; Rison Consulting (Pty) Ltd 2001). The interconnected nature of the underground workings also highlighted the need for integrated, regional solutions to be developed (Pulles *et al.* 2005; van Tonder *et al.* 2008). By and large, solutions have hinged on the eventual need to pump and treat water to maintain safe water levels within the underground workings and the longer-term aim of reducing the flow of water into the underground workings as a means to reduce the eventual costs of pumping and treatment (Krige 1999; Krige 2001; Strachan 2008).

During this period, the existing problems and threats due to the flooding of the underground workings rose to prominence in the public eye, often attracting sensationalist media reports of impending disaster. In the second half of 2010, the South African Government appointed an Inter-Ministerial Committee, representing the Ministries of Mineral Resources, Water Affairs, Environmental Affairs and Science and Technology and the National Planning Commission to investigate the issues surrounding acid mine drainage and make recommendations for a programme to manage it. This committee appointed a team of experts led by the Council for Geoscience combining the expertise within the relevant government institutions, science councils, the Water Research Commission and a number of universities. The Team of Experts produced an assessment of the situation and recommendations for a path forward.

The recommendations of this team (Ramontja *et al.* 2011), which were subsequently

Fig. 3 *Acid mine drainage generated in surface tailings deposits in the West Rand*

adopted by government combined the objectives of maintaining a safe water level by re-establishing the pumping of water from the underground workings and the reduction of volumes to be pumped via the control of surface water ingress. It was recommended that the pumped water be treated. Initially this would be by neutralisation, but it was recommended that desalination be investigated as a medium- to long-term measure. The importance of AMD sources over and above the underground mine voids, in particular diffuse sources such as surface mine residues (Steffen Robertson and Kirsten 1986; Fig. 3) was acknowledged, as was the long-term nature of the problem faced. A key gap identified is the long term funding of the process as many of the mines involved closed in the past when the legislative requirements for mine closure were not as strict as they are today. The need for enhanced water quality and flow monitoring was also recommended.

These recommendations were adopted by the South African Government in February 2011. Structures were put in place to oversee their implementation. The initial priorities were identified as the control of the discharge of AMD to the environment in the Western Basin and the prevention of the rise of the water levels to critical levels in the Central and Eastern Basins. During the months that followed, significant progress was made in the appointment of implementing agents and the commissioning of detailed feasibility studies. At the same time a process was initiated to undertake a feasibility study for a long-term solution to deal with AMD in the Witwatersrand (Department of Water Affairs 2012).

Implementation of solutions

Since 2011, South Africa's Department of Water Affairs has been overseeing the process of implementing measures aiming to prevent the rise of water above environmentally acceptable levels in the Central and Eastern Basins and to lower the level in the already flooded Western Basin. This programme incorporates measures to neutralise water pumped from the underground mine workings. An existing neutralisation plant in the Western Basin has been upgraded such that it has sufficient capacity for the volume of water required to control the water level, while infrastructure has been developed to pump this volume of water from the Basin.

As a consequence, no untreated water has been discharged to the environment in this area since mid-2012 (Hobbs 2013). A programme is in place for the installation of pumping and treatment infrastructure in the Central and Eastern Basins, although funding of this remains a challenge.

In parallel with this process, the Council for Geoscience (South Africa's Geological Survey) and the Department of Mineral Resources are undertaking a programme to understand the ingress of water into the underground workings and implement measures to reduce these flows (Strachan 2008). This work comprises a programme of research into the hydrology and geohydrology of the gold fields as well as construction work aimed at reducing water ingress into the mine workings. A canal has been constructed in the west of Johannesburg, in an area where a surface stream crosses an area of historical surface mining and shallow undermining and feasibility studies are proceeding for the construction of additional canals.

Challenges

Despite significant progress, this process has not been without problems:

- Funding for the development and implementation of solutions is limited although significant funds have been forthcoming from the South African government. In addition, the DRDGold has made land available and Central Rand Gold has provided equipment for these interventions. The issue of who is liable for costs has also not been fully resolved (Nicolson 2013).
- Concerned citizens' groups have complained that the level of public participation in these processes has not been adequate and that their concerns are not being taken into account, although comprehensive statements of concern (Pretorius and Liefferink 2011) have been submitted. Environmental activists also complain about government institutions not being forthcoming with information (pers. comm. M Liefferink 2013)
- The current interventions in largely-abandoned mining areas are hampered by a lack of monitoring data and other information and the fragmentation of information between different institutions. This has necessitated the adoption of conservative remedial interventions which may involve unnecessary costs being incurred.

Conclusions

More than a century of mining in the Witwatersrand has left a significant water legacy which will persist far into the future. However, concrete interventions are taking place to bring the situation under control and prevent serious environmental problems from developing. Existing environmental problems are also being managed to limit their impacts. Local and regional considerations will necessitate the upgrading of many of these interventions in the medium- to long-term.

Flooding mines and large point-source discharges of acid mine drainage have captured the attention of the South African media. It is important to realise that these are not the sole sources of polluted water entering the environment as a result of gold and uranium mining in the Witwatersrand region. These will also need to be addressed to address local and regional water pollution.

The processes undertaken to address acid mine drainage in the older gold fields of the Witwatersrand has been hampered by a shortage of reliable data on historical water flows and quality. While this cannot be remedied, it emphasises the need to ensure that sufficient data are collected to optimise the regional closure processes which will occur in the future in other related mining areas.

References

Coetzee, H., Croukamp, L., Venter, J. and de Wet, L. (2005) Contamination of the Tweelopiesspruit and environs by water from the Western Basin decant point on Harmony Gold's property., Council for Geoscience, Report No. 2005–0148, Pretoria: 28p.

Coetzee, H., Nengobela, N. R., Vorster, C., Sebake, D. and Mudau, S. (2008) South Africa's strategy for the management of derelict and ownerless mines. Mine Closure 2008: Proceedings of the third international seminar on mine closure. A. Fourie, M. Tibbett, I. Weiersbye and P. Dye. Johannesburg, Australian Centre for Geomechanics:113–124.

Coetzee, H., Winde, F. and Wade, P. (2006) An assessment of sources, pathways, mechanisms and risks of current and future pollution of water and sediments in the Wonderfonteinspruit Catchment, Water Research Commission, WRC Report No. 1214/1/06, Pretoria: 202p.

Department of Water Affairs. (2012) "Acid mine drainage: Long term solution feasibility study." Retrieved 11 April 2013, from www.dwaf.gov.za/ Projects/AMDFSLTS/default.aspx.

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

Hobbs, P. J. (2013) Pilot implementation of a surface water and groundwater resources monitoring programme for the Cradle of Humankind World Heritage Site, Council for Scientific and Industrial Research, CSIR/NRE/WR/ER/2013/0023/B, Pretoria: 56p.

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

Hocking, A. (1986) Randfontein Estates: The first hundred years. Bethulie, Hollards, 280p.

Janse van Vuuren, A. (2011, 8 June 2011) "Acid drainage claims another shaft." MiningMX Retrieved 11 April 2011, from www.miningmx.com/news/ gold_and _silver/Acid-drainage-claims-another-shaft.htm.

Krige, W. G. (1999) An investigation into groundwater recharge derived from the upper Klip River tributaries where these cross the Main, Bird and Kimberley Reef outcrops and associated shallow mine workings, African Environmental Development: 14p.

Krige, W. G. (2001) A quantification of water volumes recharging the central rand mine void, associated with direct ingress from surface water sources, African Environmental Development.

Nicolson, G. (2013) "Joburg's acid mine drainage: Swapping sludge for salt." Retrieved 14 April 2013, from www.dailymaverick.co.za/article/2013-03-15-joburgs-acid-mine-drainage-swapping-sludge-for-salt/#.UWq597W7K9Q.

Pretorius, K. and Liefferink, M. (2011) Detailed Response to The Findings and Recommendations of Report to the Inter-Ministerial Committee on Acid Mine Drainage (December 2010), Federation for a Sustainable Environment: 64p.

Pulles, W., Bannister, S. and van Biljon, M. (2005) The development of appropriate procedures towards and after closure of underground gold mines from a water management perspective, Water Research Commission, WRC Report No. 1215/1/05, Pretoria: 138 p.

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 Inter-Ministerial-Committee on Acid Mine Drainage, Pretoria: 146p.

Rison Consulting (Pty) Ltd (2001) Geological and Geohydrological control on the groundwater ingress into the central rand basin.

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, Water Research Commission, WRC Report no 486/1/95, Pretoria: 238p.

Steffen Robertson and Kirsten (1986) Report on the feasibility of emergency water supply from wells, Gemsbokfontein Compartment, prepared for Johannesburg Consolidated Investment Co. Ltd., SRK Report CI.5315/1.

Strachan, L. K. C. (2008) Strategy for the Management of Mine Water Ingress and Decant Problems in the Witwatersrand Gold Mining and KOSH Areas, South Africa, Council for Geoscience, unpublished, Pretoria.

van Tonder, D. M., Coetzee, H., Esterhuyse, S., Msezane, N., Strachan, L., Wade, P., Mafanya, T. and Mudau, S. (2008) South Africa's challenges pertaining to mine closure – The concept of regional mine closure strategy. Mine Closure 2008: Proceedings of the third international seminar on mine closure. A. Fourie, M. Tibbett, I. Weiersbye and P. Dye. Johannesburg, Australian Centre for Geomechanics:87–98.