Management of water levels in the flooded mines of the Witwatersrand, South Africa

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Abstract

Following the cessation of underground mining in the three original mining complexes in South Africa's Witwatersrand Gold Field, mines started to flood with no control measures in place. In 2002, acidic water began to discharge from the West Rand Gold Field's underground workings, negatively impacting on the downstream environment, with impacts identified in both surface and underground water. In the years following this, underground operations ceased in the Central Rand and East Rand Gold Fields and the underground workings were allowed to flood.

Three approaches have been identified for the management of the flooded underground workings:

- Flooding and management of the discharge at surface.
- Maintaining the water level at a pre-determined safe level, locally referred to as an "environmental critical level" by pumping.
- Controlling the water level in the underground workings by means of a discharge tunnel.

Currently, pump and treat programmes are at various stages of development and implementation in the three original gold fields. Planning for these has been severely hampered by a lack of reliable historical data on volumes pumped. The absence of supporting data also led to the selection of conservative environmental critical levels, which will be extremely costly to maintain.

Adjustment of the environmental critical levels in the Witwatersrand Mines would require a good understanding of both the hydrodynamics of the relevant underground mine workings and the local hydrology and hydrogeology in the areas likely to be impacted, but would reduce pumping costs and could allow the implementation of gravity-driven drainage in some areas. It may also have a positive impact on the rate of flow into the underground workings and on the water quality in the longer-term.

Key words: Witwatersrand, Acid mine drainage, pumping, prediction

Introduction

Gold was discovered in what is now the City of Johannesburg in an outcropping conglomerate of the Witwatersrand Supergroup in 1886. Since the initial discovery, the Witwatersrand Basin, including the early discoveries in and around Johannesburg and the entire "Golden Arc" extending along a strike length of more than 300 km has yielded over 2 billion ounces of gold (Chamber of Mines of South Africa Accessed 2016) and more than 150 thousand tons of uranium (Nuclear Energy Agency 2014). Mining commenced almost immediately, extending rapidly along the outcrop to the West and the East. Three gold fields - The East Rand, West Rand and Central Rand (**Figure 1**) - were defined, based on zones of contiguous outcrop and suboutcrop of the gold bearing strata. These conglomerate layers were mined down-dip to depths of as much as 3 000 m in these areas. Soon after the commencement of surface mining in 1886, the surface workings intersected the local water table, necessitating the pumping of water from the workings (pers. comm. N Lane). As the early surface workings gave way to larger-scale underground workings, the need to pump water increased. At the same time, the underground workings of adjacent mines were connected to each other, allowing mines to share infrastructure as well as providing emergency access to the workings. This trend continued until the three large complexes of interconnected underground mines had developed.

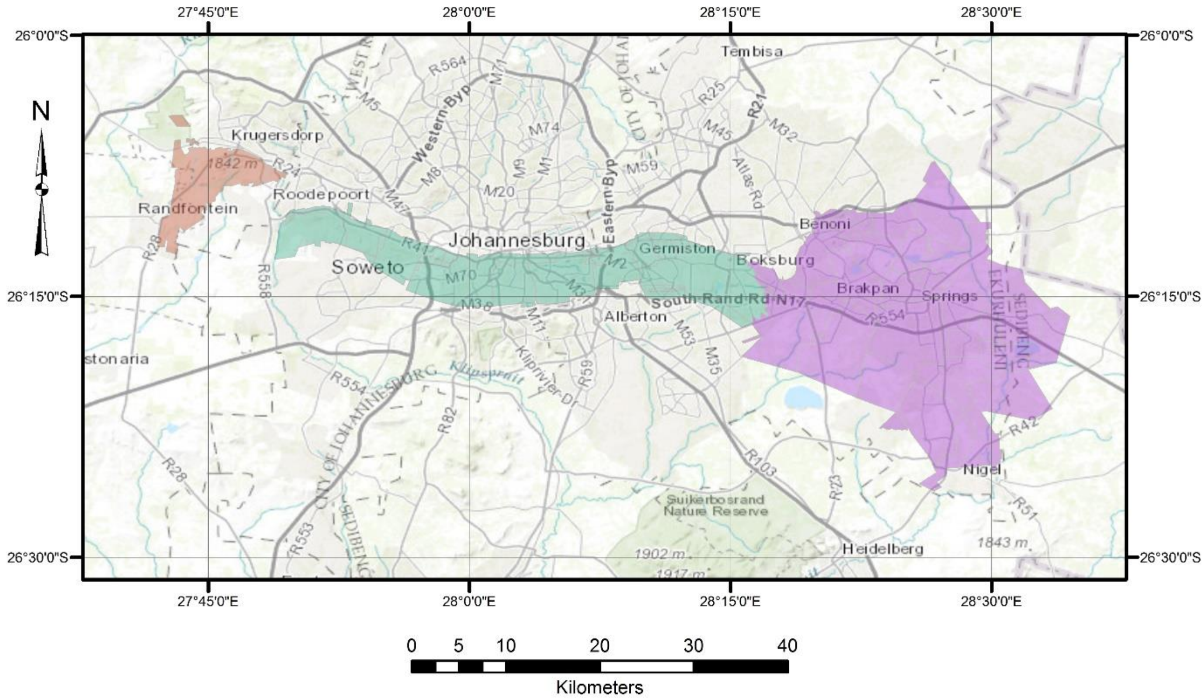

Figure 1. *Locality of the three original Witwatersrand Gold Fields, in and around the City of Johannesburg.*

Closure and flooding of mines

During the second half of the 20th Century, a combination of resource depletion and economic factors led to the successive closure of the mines in these three gold fields. The interconnection, which had optimised pumping when all mines were operational now began to count against the remaining mines, with adjacent mines discharging into each other via the inter-mine openings. As more and more mines closed, the responsibility for pumping fell onto fewer and fewer mines until the last operating mines – Randfontein Estates in the West Rand, East Rand Proprietary Mines in the Central Rand and Grootvlei in the East Rand ceased pumping in the late 1990s, 2010 and 2011, respectively. In all three cases, the mines were allowed to flood.

In September 2002, water began to discharge to surface from the underground workings of the West Rand. Owing to interactions with sulfides and other minerals in the ore, the water was acidic with substantial concentrations of sulfate and metals (Coetzee et al. 2002; Coetzee et al. 2005; Hobbs and Cobbing 2007). Plans were presented to lower the water level in the mine void to below an environmental critical level (ECL), initially looking only at surface discharge from low-lying shafts and adjacent springs and later revised to prevent contamination of groundwater. Pumping to achieve this objective commenced in April 2012 (Borralho 2014).

The prediction of the likely discharge rate from the underground workings in each of the gold fields is hampered by the limited historical records of volumes pumped which are available. Estimates of the volumes pumped during periods of active mining in the Central Rand and East Rand have been presented by Scott (1995), while Coetzee (2008) highlights the lack of reliable information to predict a discharge or required pumping volume for the West Rand.

Definition and establishment of Environmental Critical Levels

In 2010, following the impacts of the discharges in the West Rand and with the cessation of pumping imminent in the Central Rand and East Rand, an Inter-Ministerial Committee was established to assess the situation and recommend measures to manage the impacts of mine water in the Witwatersrand. A Team of Experts was appointed which delivered a report early in 2011 (Ramontja et al. 2011). This report recommended that water be pumped from the underground workings and that the water level be maintained at a level which will not lead to any surface discharge or groundwater contamination (Lin and Hansen 2010; van Biljon 2011).

Conservatively determined levels were identified, allowing for the prevention of surface discharge and the maintenance of the water level below any potentially useful aquifers as well as providing a buffer to allow for high recharge levels during particularly wet years. These levels, along with the historical water levels and likely surface discharge levels are shown on Figures **2** to **4** and **Table 1**.

Table 1. *Environmental Critical Levels for the three original Witwatersrand Gold Fields (Lin and Hansen 2010; Ramontja et al. 2011; van Biljon 2011)*

Gold field	ECL (m a.m.s.l.)	Rationale
West Rand	1530 m	Prevent discharge to surface and adjacent dolomite aquifer.
Central Rand	1503 m	Prevent discharge to surface and groundwater in lowest-lying portions
East Rand	1150 m	Maintain water level below dolomite where this overlies the mines and could have potential for groundwater supply

These levels were set conservatively, *i.e.* it may be possible to adjust them to shallower depths, saving pumping costs. However, this would require additional information regarding shallow groundwater levels and qualities to set a baseline and monitoring of the effect of mine flooding on the surrounding aquifers. Monitoring boreholes would be required to provide an early warning capacity to detect discharge from the mine voids to adjacent aquifers. Sufficient pumping capacity would also be required to lower the water level in response to indications of discharge or increased recharge during periods of high rainfall and above-average recharge.

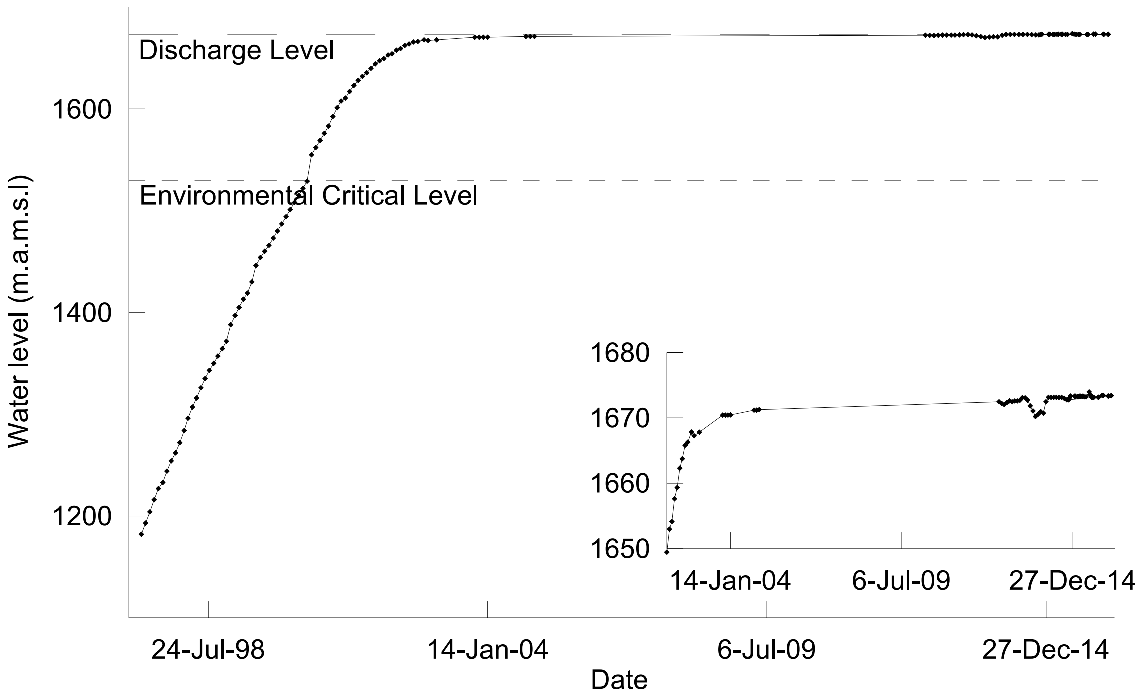

Figure 2. *Flooding of the underground workings of the West Rand Gold Field, 1997-2016 (Data compiled from monitoring of Randfontein Estates: Central Vent Shaft, Randfontein Estates: 18 Winze and Randfontein Estates No. 8 Shaft. Monthly average levels are presented for data collected since 2002). Inset graph shows recent data, since the first surface discharge and after the commencement of pumping.*

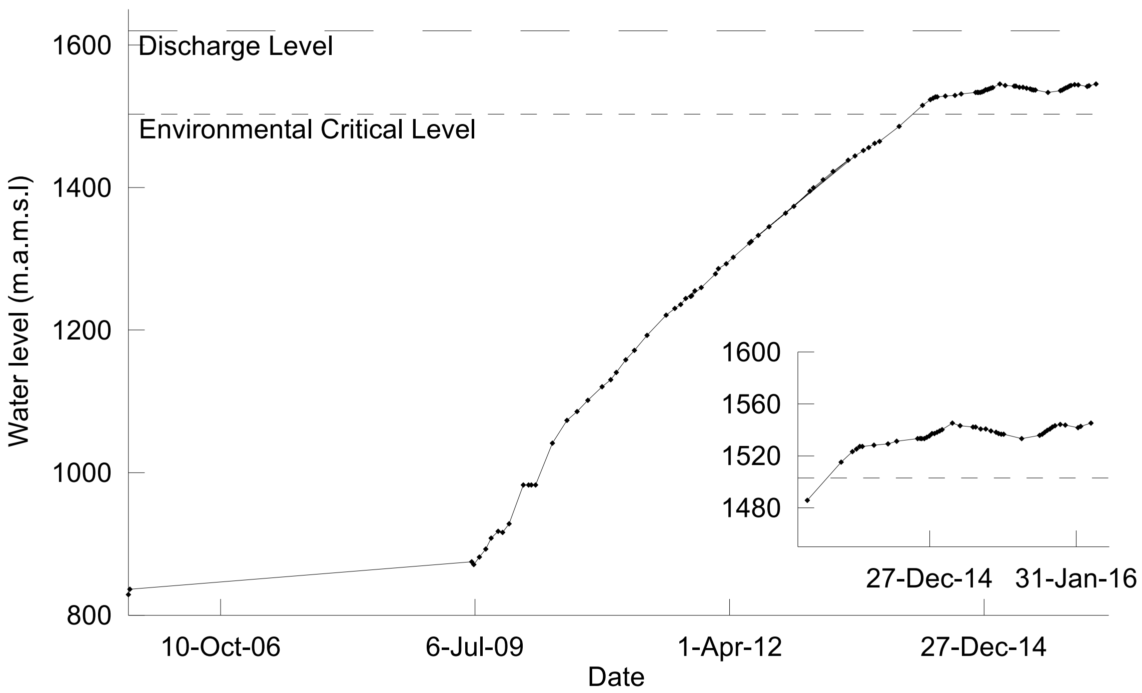

Figure 3. *Flooding of the underground workings of the Central Rand Gold Field, 2005-2016 (Data from Crown Mines No. 14 Shaft). Inset graph shows recent data, after the commencement of pumping.*

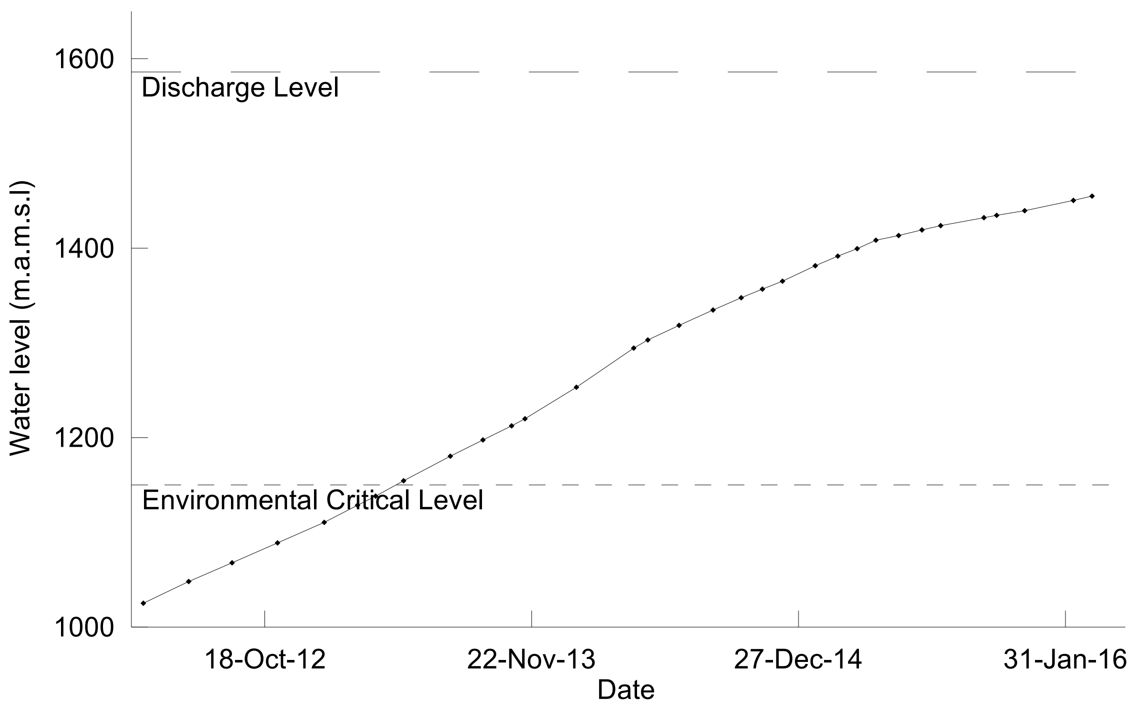

Figure 4. *Flooding of the underground workings of the East Rand Gold Field, 2012-2016*

Mine flooding and protection of the relevant Environmental Critical Levels

Figures **2** to **4** show the historical water levels in the underground workings of the three original Witwatersrand Gold Fields.

In the West Rand, water breached the surface before pumps were installed and has discharged through the lowest lying shaft continuously since then, with the exception of a period in 2013, when sufficient water was extracted from the void to lower the level by a few meters (inset graph on **Figure 2**). The volumes pumped have not been sufficient to control the water level within the underground workings. This may be exacerbated by the discharge of a wet tailings slurry into the void, which will displace water, requiring additional volume to be pumped to compensate for the volume it occupies.

In the Central Rand, the conservative ECL was breached before the pumps were commissioned in 2014. Water levels recorded since then show a small net rise, with a seasonal trend indicating increased recharge during the wet summer season. It is of concern that water levels have risen during the 2015/16 wet season, despite the region experiencing a severe drought. Nevertheless, no groundwater contamination has been reported in low-lying areas.

Similarly, the ECL in the East Rand has been breached. The pumps required to control the water level are scheduled to be commissioned during the course of 2016, after which an assessment of their effectiveness in controlling the water level within the underground mine workings can be assessed.

Potential relaxation of the environmental critical levels

The immediate effect of pumping from a shallower depth will be a substantial reduction in the pumping costs, which are large, given the volume, potentially totaling more than 200 ML/d across the three gold fields. Even a reduction in pumping depth of a few metres can have a substantial effect on costs, especially as the pumping and treatment of water is seen as a long-term measure.

Additional benefits of a shallower ECL may be the opening up of new options for water management in the long term. These include the construction of gravity-fed discharge tunnels (Council for Geoscience 2004), allowing the control of the water level within the underground workings without pumping, using a tunnel intercepting the workings at an appropriate level. Previous work on such a tunnel in the Central Rand identified this possibility but was deemed too costly, given the conservative estimates for the ECL which would require a very long tunnel to drain the underground workings at an appropriate level.

Groundwater quality is still not routinely monitored in all areas likely to be affected by rising water in the underground mine workings. The potential use of groundwater needs to be assessed in the low-lying areas within the gold fields to inform cost-benefit analysis to determine an optimal water level, balancing possible pollution against the cost savings which would result from pumping from shallower depths. An assessment of current groundwater quality in potentially affected areas is also required to determine the pre-existing impacts of surface activities and infrastructure on groundwater, in particular mine residue disposal.

Conclusions

The lack of provision for mine planning as part of the mine closure process in the three original Witwatersrand Gold Fields led to a situation where mines were abandoned and allowed to flood without sufficient information being available for detailed prediction of the rates of flooding and the possible consequences of water levels being allowed to rise in an uncontrolled fashion. This has led to a situation where an adaptive approach to mine water management needs to be adopted, based on limited information and conservative assumptions.

The breaching of the environmental critical levels has led to a situation where impacts need to be assessed and decisions regarding lowering of water levels based on ongoing impact assessment. The cost of lowering the water level in the underground workings is likely to be substantially greater than the cost of maintaining it, as, given the limited ability to maintain the water level in both the West

Rand and Central Rand, additional pumping infrastructure will be required to lower it. An adaptive approach can also be adopted, in which regular monitoring of groundwater levels and quality in the area likely to be impacted by rising water in the underground workings is undertaken and the results used in the determination of an optimal water level.

Water levels in the underground workings, volumes of water pumped and discharged are currently well monitored. This information, along with rainfall data will provide a fuller picture of the hydrodynamics of the Witwatersrand mines, assisting in the search for sustainable solutions to mine flooding.

The lessons learned from the three oldest gold fields in the Witwatersrand provide important insight into the management of the closure of other large interconnected complexes of underground mines. Better understanding of the volumes of water which need to be managed as well as the flow dynamics, seasonal variations etc. are essential to minimise long-term liabilities at closure.

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