Water management strategies to reduce long-term liabilities at Grootvlei gold mine

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ABSTRACT

Grootvlei is one of the last remaining gold mines operating within the East Rand mining basin in Gauteng Province, South Africa. In order to gain access to the gold reserves, underground mine water is pumped from the mining basin at an average rate of 75 mega-litres per day. This water is currently treated at a High Density Separation plant to remove iron and condition pH levels, before it is discharged into a local river, the Blesbokspruit. A portion of this river down stream of the mine discharge point was declared as an international RAMSAR wetland. The mine water contains high levels of dissolved salts and the discharge impacts on the downstream river water quality. Water from the river is not only used for irrigation down stream of the mine, but the Blesbokspruit also contributes to the Vaal Barrage, which supplies drinking water to Gauteng Province. Grootvlei mine is in the process of developing methods to reduce the impact of discharge on the Blesbokspruit. The study focuses on two main objectives, namely to reduce the volume of water pumped from underground and secondly, to determine the feasibility of phasing in a modular water treatment facility. Prior to this investigation, it was thought that more than half the water pumped from underground is simply industrial discharge recycled back into the mine workings through the Blesbokspruit. If the volume of water pumped from underground can be reduced effectively, the long-term cost of water treatment will be minimized. Information obtained from aerial photography, isotope composition of surface and groundwater, soil survey, a hydrogeological investigation and underground seepage rate measurements have indicated that the largest volume of underground seepage is derived from a dolomitic aquifer overlying portions of the mining area and that much less water than originally thought infiltrates from surface. This complicated the situation, as very little can be done to effectively reduce seepage from the aquifer. A number of methods to reduce recharge from surface have been evaluated during the study including canalisation of industrial and river water, sealing of subsidence along the gold bearing outcrops, improving river flow conditions, reducing areas of ponding over shallow undermined

ground, grouting of faults and underground water management. This paper discusses the results of the investigation as well as the implementation of measures to reduce underground seepage rates.

1. BACKGROUND

The Grootvlei Proprietary Mines Limited, a subsidiary of Petrex (Pty) Ltd, is one of the last remaining operating gold mines in the East Rand Mining Basin, Gauteng Province, South Africa (Figure 1). Mining has been ongoing in the East Rand basin over the last 80 years, with the number of active mines peaking in the 1950's. During the 1970's and 1980's gold mining activities in the area declined and by the 1990's the majority of the mines in the area closed down. Petrex currently operates three gold mines in the East Rand Mining Basin, including Grootvlei, Consolidated Modderfontein and Nigel Gold Mines, indicated as the Petrex Mineral Rights Area (MRA) in Figure 1. These mines lie along an arc of approximately 40 km from Benoni in the northwest to Nigel in the south.

The underground workings in the East Rand mining basin were dewatered from Sallies Mine until 1991, when pumping at this point ceased. The deeper regions of the East Rand basin is flooded, but Grootvlei Mine is shallower and in order to continue with its mining, pumping and discharging of underground water started in 1996 to maintain the water level below 740 m below surface. Mine water pumped from underground is discharged into the Blesbokspruit, a part of which has been declared a RAMSAR wetland, as shown in Figure 1.

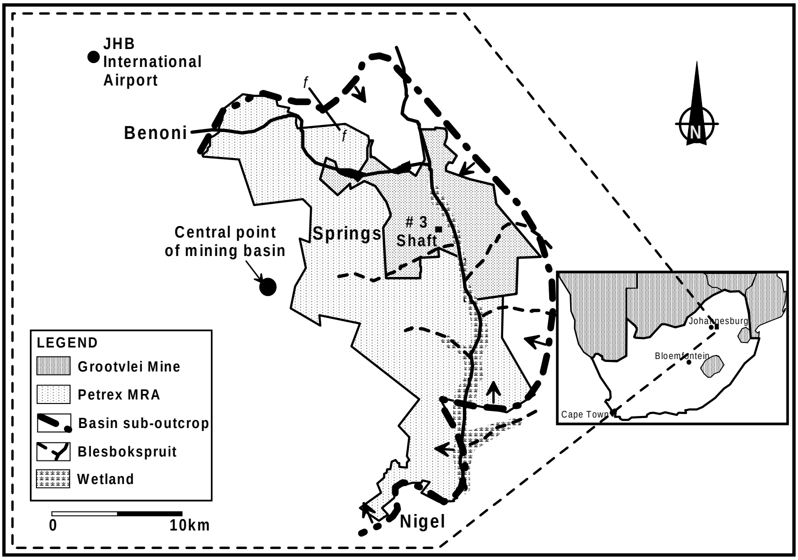
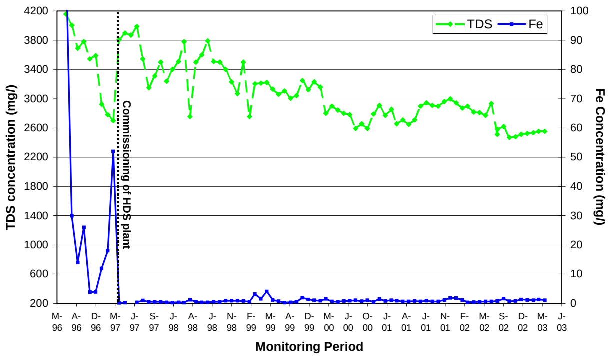


Figure 1. Location map

Historically, pumping operations from the Grootvlei No 3 shaft can be divided into three major periods. Initially, the Department of Water Affairs and Forestry (DWAF) issued a water permit in 1996 for the release of untreated underground water into the Blesbokspruit.

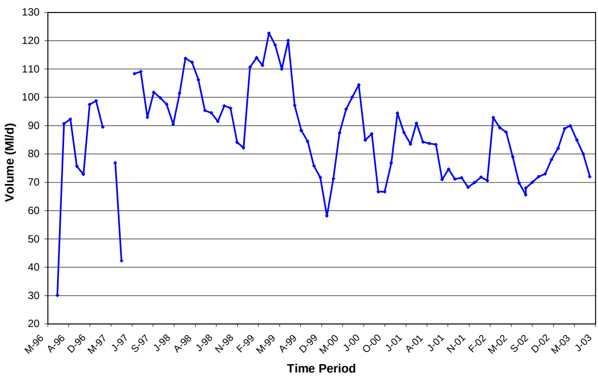
Following extensive contamination of the wetland with red iron oxide particulate matter, resulting in a number of fish and crab mortalities, this permit was withdrawn. Conditions of the succeeding permit required the construction of six temporary settling dams for the treatment of the effluent while a High Density Separation (HDS) plant was being constructed. Following the completion of this water treatment plant, DWAF issued a permit that allowed for the discharge of mine water subsequent to treatment at the HDS plant. The location of No 3 shaft is indicated on Figure 1.

Figure 2 No 3 Shaft Discharge Point Water Quality



The construction and installation of both the temporary settling ponds and the HDS plant resulted in a progressive improvement in the quality and reduction of the toxicity of the treated effluent. Although the HDS plant is effective in reducing the iron concentrations in the mine water from more than 180 mg/l to less than 1 mg/l, the water discharged into the Blesbokspruit still contains high dissolved salt concentrations, specifically sulphate, calcium, magnesium, sodium and chloride (Figure 2).

Figure 3 No 3 Shaft Discharge Volumes



In order to keep the mining basin dry, water is pumped from the underground workings at an average rate of 75 mega litres per day (Ml/d). The pumping rates vary seasonally, as shown in Figure 3, between 30 and 120 Ml/d historically. Under the current water use license, the mine is allowed to release up to 96 Ml/d of HDS treated water.

One of the medium- to long-term objectives of the mine water license is the implementation of water treatment to produce water of improved quality. Due to the high cost of water treatment, the mine is investigating methods to reduce the volume of water pumped from underground, thus reducing long-term treatment costs. This study focus on the process followed to identify methods of reducing underground seepage volumes.

2. GEOLOGY AND HYDROGEOLOGY

The geology of the area plays a major role in the rate of underground seepage. The geological setting of Grootvlei Mine is shown in Figure 4 and can be summarised as follows:

Karoo Supergroup	Middle Ecca (shale, sandstone, coal)
	Dwyka (shale, sandstone, tillite)
Transvaal Supergroup	Malmani Dolomite
	Black Reef (shale, quartzite, conglomorate)
Witwatersrand Supergroup	Kimberley Reef
	Main Reef
	Jeppestown Formation (shale, sandstone)

A syncline dipping slightly to the southwest forms the East Rand mining basin. The extent of the mining basin within the study area is shown in Figure 1. Structural patterns control seepage of water into the underground workings. Dykes and sills of at least four different ages have intruded into the Witwatersrand sediments.

The main aquifer present is a dolomitic aquifer that forms part of the Transvaal Supergroup. In the northern part of the mining area the dolomite overlies Witwatersrand sediments, where it is up to 200m thick. A prominent set of sills occurs in the dolomite below 60m, referred to as the Green sill. These sills have resulted in the development of perched aquifers. Due to the depth of mining, the perched aquifers are not significantly affected by mining activities. Major faults and fissures occur from the dolomitic aquifer into the underlying mine workings, most significantly in the Black Reef workings since much of the off reef developments is in dolomite (Figure 4).

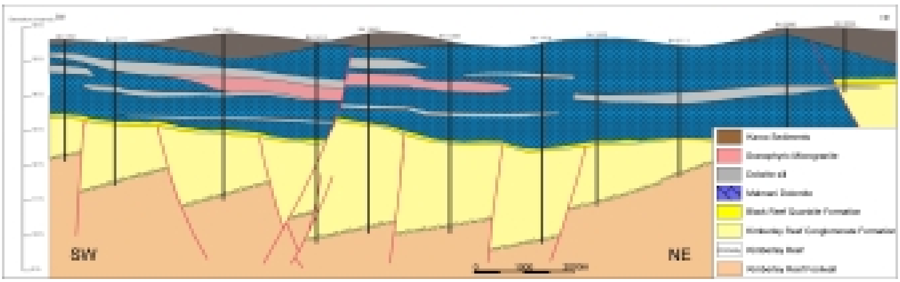


Figure 4. SW – NE cross section through Grootvlei Mine

Three main mechanisms of recharge to the underground workings exist, namely recharge from the dolomitic aquifer, direct recharge along reef outcrops and seepage from the Blesbokspruit.

The rate of recharge to the dolomitic aquifer was estimated using the environmental chloride method (Scott, 1995) to be approximately 30 Ml/d, which is 16 – 20 % of the mean annual precipitation. Direct recharge along reef outcrops occurs mainly in periods of excessive flooding along the northeastern reaches of the Blesbokspruit in the vicinity of Benoni (Figure 1). In this area, the mining stopes extend to surface and are associated with extensive subsidence. Based on surface runoff volumes, it is estimated that the rate of direct recharge along reef outcrops varies between 2 and 3 Ml/d. Historically it was thought that the Blesbokspruit is a steady source of water inflow into the underground workings via faulting planes and geological intrusions. The river is further thought to contribute to the recharge of the dolomitic aquifer.

In order to understand the recharge mechanism from the Blesbokspruit, a soil survey was undertaken within the flood plain of the river. The results of the survey showed that alluvial clays to depths of 1.5m are present along large stretches of the river. The clays effectively retard infiltration from the river to the underlying mines. Direct infiltration from the Blesbokspruit into the underground workings was therefore not considered to be as significant as originally thought. Seepage from the Blesbokspruit was therefore assumed to form part of the regional recharge to the dolomitic aquifer. As it became apparent that the probability of large volumes of water seeping from the river into the mine workings over the entire catchment is low, the study focussed on identifying specific areas of infiltration to the underground workings.

3. STABLE ISOTOPE STUDY

In order to assess the relative contribution of groundwater and surface water to the underground workings at Grootvlei Mine, water samples were taken from 53 locations for oxygen and hydrogen isotope compositions.

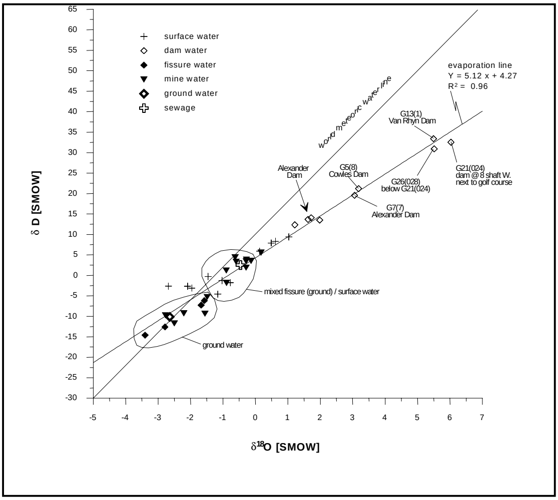


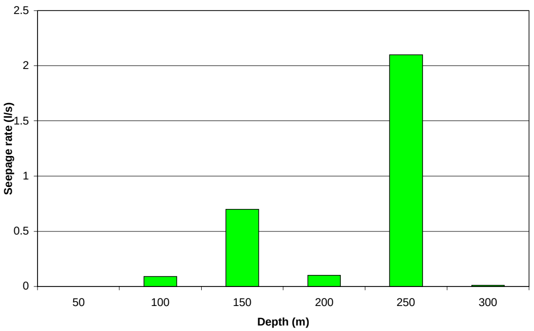
Figure 5. Oxygen vs. Hydrogen Isotopic Composition. The world meteoric water line (WMWL) was adopted after Craig (1961) as $\delta D = 8 \times \delta^{12}O + 10$. All samples plot along an evaporation line with a lesser slope relative to the WMWL (after Horstmann, 2003).

The potential for assessing the relative contribution of surface and groundwater to the underground workings arise from variations in oxygen and hydrogen isotope composition. This method relies on the conservative behaviour of isotopes of the major constituents of water (oxygen and hydrogen). The results of the analysis are shown in Figure 5, and calculations based on average end-member compositions indicate that surface water contributes only 40 % of the underground mine water (Horstmann, 2003). This value is reduced to less than 30 % if only higher evaporated surface waters from dams are taken into account. Between 60 and 70 % of the underground water is derived from ground and/or fissure water. This confirms the results of the soil survey discussed above.

4. IDENTIFICATION OF AREAS WHERE INFILTRATION FROM SURFACE WATER OCCURS

A survey of underground seepage rates was undertaken to profile the depth of water inflow rates. The information obtained indicated that the water seepage occur to depths of 300 m below surface. This depth was used to identify areas were shallow undermining is associated with the Blesbokspruit, dams or ponding of surface water, geological features that act as conduits to the underground workings as well as areas of subsidence. A total of six areas of risk for infiltration from surface were identified in this way. These are shown in Figure 7 and are discussed below.

Figure 6 Underground seepage with depth



4.1 SEALING OF SUBSIDENCE ALONG THE NORTHERN OUTCROP

Direct rainfall recharge via subsidence associated with shallow mining of the Main Reef outcrop in the northern part of the study area is estimated to be 2.5 Ml/d of the wet season recharge of 108 Ml/d. During the dry season no recharge takes place along the northern outcrop. Remediation options proposed for this area include:

- Rehabilitation of areas of subsidence undertaken by Petrex as part of opencast mining in this area.
- In areas where mining will not take place, ground affected by subsidence will be backfilled and rehabilitated to ensure free drainage.
- Areas of rehabilitated subsidence will be made free draining to limit infiltration during the wet season.

4.2 SURFACE PONDING OVER SHALLOW UNDERMINING IN THE NORTH

Surface water influx to the mining basin via this area is estimated to be 42 Ml/d of the total wet season recharge and 7 Ml/d of the total dry season recharge of 71 Ml/d. In this area shallow undermining of the Main Reef is overlain by wetlands and surface ponding. A number of remediation options were considered for this area, including:

- Construction of a low flow channel for the Blesbokspruit past the areas of shallow undermining and ponding.
- Backfilling the borrow pits in which water is ponding and implementing measures to divert surface runoff around backfilled areas.
- Enhance flow within the channel by means of reed control.
- Canalising industrial discharges upstream of the area past shallow undermining and ponding. This will reduce the dry season flows and may assist with reed control over the winter months.
- Seal defunct mine shafts present in the area that are loosing water to the underground workings.

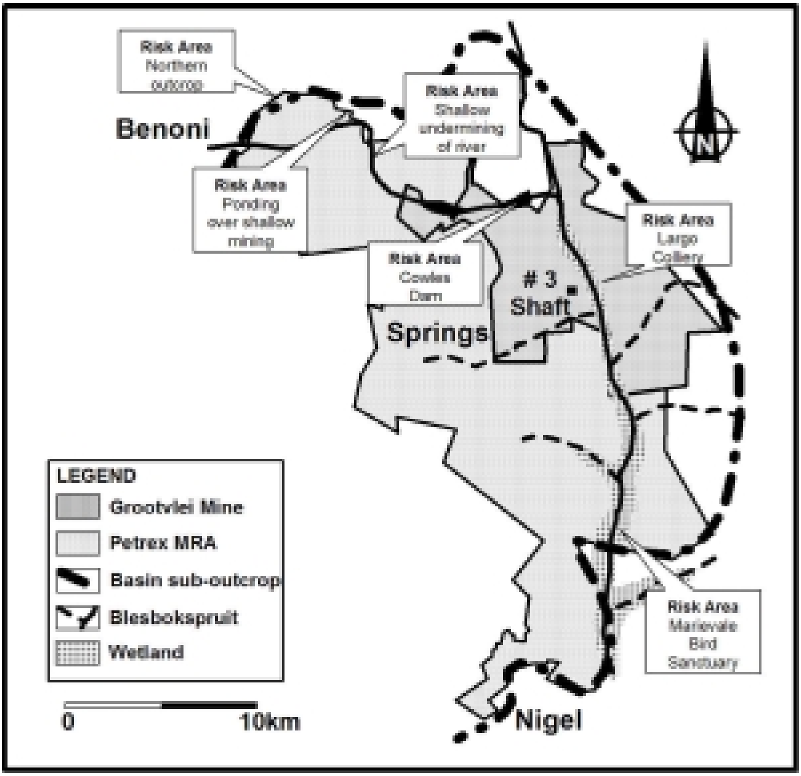


Figure 7 Areas of high risk for infiltration of surface water to the mines

4.3 SHALLOW UNDERMINING OF THE BLESBOKSPRUIT IN THE NORTH

It is estimated that surface water inflow through areas of shallow undermining of the Blesbokspruit in the north of the catchment could be as high as 24 Ml/d constantly during the wet and dry seasons. In this area, mine stopes are in places only 7m below the river and evidence of subsidence in the floodplain was recorded during the investigation. Significant ponding of the Blesbokspruit occurs in this area due to insufficient drainage underneath roads.

Remedial measures proposed for this area are aimed at creating a defined channel and a seasonal wetland instead of an area of permanent ponded water over shallow undermining. This includes:

- Dredging of silt close to the culverts as well as upstream to create a channel for water flow.
- Excavate silt material downstream of the culverts to facilitate drainage.
- Installation of additional drainage pipes under the road to reduce flow constriction and future sedimentation.
- Stabilisation of the low flow channel using rock riprap where required.
- Enhancing the amenity value of the area for adjacent communities through landscaping of the area.

4.4 FAULT ASSOCIATED WITH COWLES DAM

A fault was identified in the vicinity of Cowles Dam, situated in the flow channel of the Blesbokspruit, which could potentially act as a conduit between the dam and the underground mine. This fault was traced through the dolomitic aquifer into the underground workings in an area referred to as “the rainforest”. It is estimated that infiltration along this fault could be 10 Ml/d persistent during the year. Insufficient information is presently available regarding the intersection point with the Blesbokspruit. An independent company has proposed to drain Cowles Dam to dredge and process the gold tailings deposited in the dam. Once this project is underway, the basin of the dam will be inspected and the location of the fault will be determined with the aid of geophysical methods. At the same time, underground seepage rates in “the rainforest” will be measured to determine the effect of drying the dam out on water ingress into the mine. Once this information is available, accurate remediation strategies can be developed to minimize the effect of seepage along the fault plane into the mine.

4.5 SEEPAGE FROM SUBSIDENCE ASSOCIATED WITH LARGO COLLIERY

Largo Colliery is a defunct coalmine that closed in 1953. As such rehabilitation of the mine is considered to be the responsibility of the Department of Minerals and Energy (DME). The DME has recently launched a project during which infiltration of surface water into defunct mines within Gauteng will be minimized. Rehabilitation of Largo Colliery will be addressed as part of this project.

Due to shallow underground mining of three coal seams, also underneath the Blesbokspruit, significant areas of subsidence have developed in the flow channel as well as along the eastern bank of the river. Information obtained from monitoring boreholes drilled between the coalmine and the river indicate that the defunct coalmine is direct contact with the dolomitic aquifer, thus contributing to the overall underground water make at Grootvlei mine.

4.6 SHALLOW UNDERMINING IN THE MARIEVALE BIRD SANCTUARY

It is estimated that up to 24 Ml of water could infiltrate along areas of shallow undermining in the southern part of the catchment, most notably in the wetlands associated with the Marievale Bird Sanctuary. The bird sanctuary forms part of the RAMSAR wetland in the Blesbokspruit catchment. The Blesbokspruit is also ponded over large stretches in this area due to insufficient drainage underneath roads. The following remediation options are considered for this area:

- Dredging of the river above the road bridge as well as upstream to create a flow channel.
- Reed management to improve water flow

- Installation of new culverts underneath the road to increase flow and reduce the wet footprint over shallow undermined ground.
- Fitting gates to the culverts to manage the water level fluctuations in the wetland on a scientific basis.

5. CONCLUSIONS

Grootvlei Mine is in the process of implementing measures to reduce the ingress of surface water into the underground workings. By doing so, the volume of water pumped from underground will be minimized, which will reduce long-term mine water treatment costs. Reduced pumping volumes and water treatment will further work towards improving the water quality in the Blesbokspruit and ultimately the Vaal River Barrage, which supplies water to Gauteng Province.

Six areas of infiltration were identified during the investigation. The expected contribution of each area is discussed in this paper. It is not anticipated that the total infiltration volume will be eliminated through the remediation measures suggested above. If rehabilitation is undertaken successfully, it is expected that the volume of water pumped from No 3 shaft may be reduced by 30 Ml/d, as shown in Table 1.

Table 1 Expected reduction in underground seepage volumes

Area	Estimated reduction
Areas of subsidence associated with the northern outcrop	2 – 3 Ml/d
Ponding over shallow undermining in the north	Up to 10 Ml/d
Shallow undermining of river in north	Up to 10 Ml/d
Geological fault near Cowles Dam	8 – 9 Ml/f
Largo Colliery	Unknown
Shallow undermining in the Marievale Bird Sanctuary	Unknown
Total	**± 30 Ml/d**

In order to measure the effectiveness of the proposed remediation measures, weirs will be installed in the underground workings to calculate the volume of water reporting to the mining basin from surface as well as from the dolomitic aquifer prior and after rehabilitation has been undertaken.

A successful water management strategy for Grootvlei mine will facilitate a workable mine closure plan, which will reduce the long-term environmental liabilities of the mine.

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