Results show that man-made aquifers within the platinum mining industry in South Africa can provide a solution for future water demands

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Abstract The pilot work was done at Elands Platinum Mine (EPM) located in the northern western parts of South Africa. South Africa counts among the 40 driest counties in the world with extreme weather conditions and needs to consider both droughts and floods. As a result EPM, as part of an integrated water management plan, by default developed an artificial aquifer using an existing backfilled mining void. The project was initiated using limited data and required careful monitoring and managed. Raw water is stored in a backfilled mining void and five boreholes are used to extract and supply water to a water treatment plant. Major advantages are cleaner water which requires less filtering, reducing electricity and water purification costs, while alsolessening the carbon footprint. It reduces the risk for the Mine to lose production as a result of water shortages.The first paper presented preliminary results where as this paper presents almost four years of conclusive results whereby a backfilled mining void is used as an artificial aquifer to enhance water security and reduce water purification costs. Recently three boreholes were drilled into an old backfilled mine void at Tharisa Minerals some 40 km west of EPM and concludes that it is a repeatable option and can be used to increase assurance of supply, effectively storage of water with minimum evaporation and environmental losses and decrease dirty water discharge. If backfilling is done correctly these old mining works may in the near future become major water sources and may be able to ease the pressure on diminishing surface water resources. However, if used now while mining is still active and used primarily as process and gland service water, then it can immediately reduce the pressure on raw and clean water sources.

Key Words sustainable, platinum, integrated water management, reduce raw water, man-made aquifers

Introduction

Eland Platinum Mine is situated approximately 10 km east of the town of Brits in the North West Province, South Africa and is within the western portion of the platinum-rich Bushveld Igneous Complex (BIC). The land use is primarily agricultural with mining becoming more prominent in the last 20 years. To date most new mining developments receive their raw water from existing surface water sources, and water availability to agriculture as well as new mining developments are becoming a major concerns for sustainable economic developments. Climate variability further contributes to water insecurity and calls for new innovative water resource development and management strategies.

Integrated mine water management tools in South Africa

The Department of Water Affairs (DWA) developed the National Water Conservation and Demand Management Strategy (NWCDMS), which defines water conservation as "the minimization of loss or waste, care and protection of water resources and the efficient and effective use of water." Eland Platinum is committed to the NWCDMS and the overarching aim is to change the way the mine manage its groundwater and bring groundwater into mining as a sustainable partner, rather than as a risk to sustainability. South Africa also developed the Artificial Recharge Strategy to introduce Artificial Recharge (AR) as a water management option and give some guidance on how AR can be applied in South African conditions (DWAF, 2007/1).

An Integrated water and waste management plan (IWMP) is part of the South African water management legislation and when submitting a water use license application, technical information must be provide in the form of an IWMP (DWAF, 2007/2). The IWMP should provide details not only of the impact assessment, but also on the short and long-term management strategies, including details of a monitoring plan, measurement on whether management objectives are achieved, and reporting. Included in the document should be measures on how to optimise and re-use water.

Eland Platinum Mine, Xstrata

With intergrated mine water management philosophy in mind,Xstrata Eland Platinum Mine (EPM) developed a detailed Integrated Groundwater Resources Management Plan (IGRMP) as part of their IWMP to develop groundwater resources in advance of mining and optimize the use of groundwater resources (Botha, 2008/1). During the course of 2008 and 2009 the IGRMP was assimilated as part of the IWMP making the IWMP a continuous process to improve and optimise water resources on EPM (Botha, 2008/2).

As part of the IWMP, the Mine developed an hourly water balance simulation model to use to test different water management scenarios in terms of more effective management of mine water management (Simx Consulting, 2009). It provides a geographic correct schematic view of the Mine on a background of a Google Earth image showing all the dirty and clean water flows and storage facilities as wells as flow rates (Figure 1). Using the simulation model, scenarios were tested e.g. storage of water underground or harvesting of open pit water or effective management of tailings storage return flows.

Groundwater resource management at EPM

The area is underlain by mafic rocks of the Rustenburg Layered Suite (RLS) and forms part of the BIC. The RLS comprises of a basal Marginal Zone (norite), the Lower Zone (norite), the Critical Zone (pyroxenite, norite, anorthosite and chromititite), the Main Zone (gabbro-norite) and Upper Zone (magnetite-gabbro). The UG2 chromitite layers occur within the upper Critical Zone and are the primary mining target. In the Brits area the BIC intrudes into the Pretoria Group, and the Magaliesberg Formation forms the base of the BIC. Within the Brits area, the strata strikes NE-SW and dips towards the NW. At Eland Platinum the mining reef dips at 18º and will be mined to a depth of ≈ 1200 mbgl (Praxos 741, 2008).

The groundwater specialist investigation for the Environmental Impact Assessment (EIA) was conducted by Africa Geo-Environmental Services (Pty) Ltd (AGES) and findings from the investigation ware used as the point of departure (AGES, 2006). Improved hydrogeological understanding was gained by adapting mineral resource exploration data. As a result, hydrogeological exploration was done with great success at the Mine (Praxos 741, 2008). The local hydrogeological conditions can now be classified in three aquifer types, namely upper perched, middle weathered and fractures and lower fractured (AGES, 2006).

The upper soil zone forms a rainfall dependent perched aquifer with a thickness between 1—5 m and blow yields of less than 0.1 L/s which are not really used. The middle aquifer can be classified as a semi-confined, shallow weathered aquifer with a thickness between 5—30 m. Blow yields are between 1—5 L/s and water quality is generally poor and high in nitrates. Fault zone fractured rock aquifers forms preferential flow pathways aquifers, having a variable spatial distribution or secondary fault zone aquifers.

Poor water quality are as a result of high nitrate concentrations in borehole water samples (>25 mg/L). The upper limit for domestic water supply for nitrate is 20 mg/L (DWAF, 1996). The average TDS concentration is 740 mg/L and the average EC value is 100 mg/L. The upper limit for TDS in domestic water supply is 1000 mg/L.

Based on the aquifer conditions, a conceptual model was derived and nine stages were simulated as scenarios to determine the groundwater flow and impacts (AGES, 2006). Simulated inflow

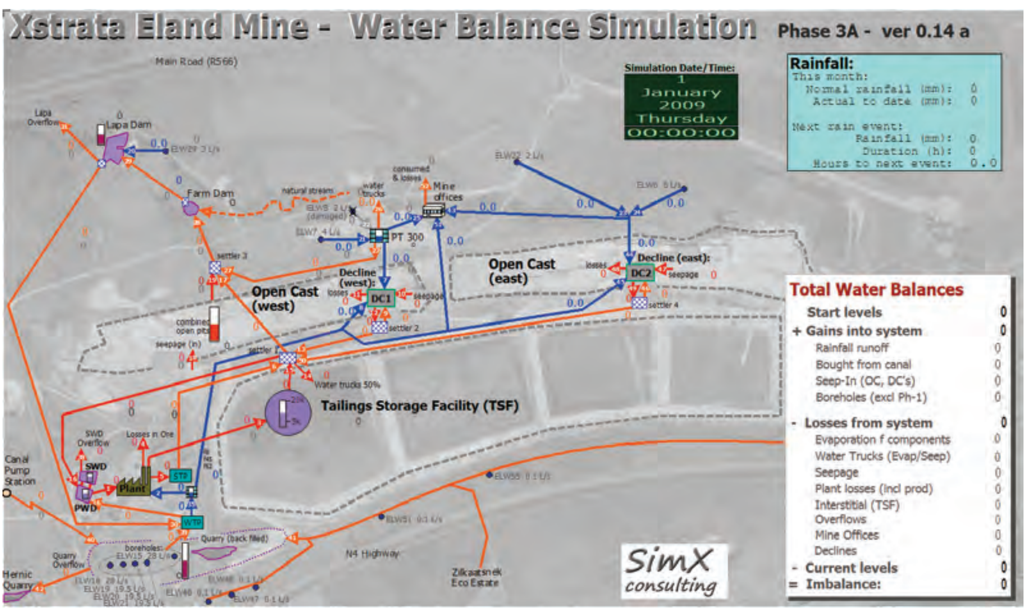

Figure 1 *Screen shot of water simulation model used at Eland Platinum*

rates into the open cast workings at the final mining depth (60 m) and calculated across the length of the open cast, are between 300 and 700 m^3/day and de-watering of the open cast mine for 5 years will lower the existing groundwater between 5 m and 15 m and might be evident up to 2 km from the open cast workings. Simulated inflow rates into the underground mine workings at a 1000 m are between 800 and 1000 m^3/day.

During the deep groundwater assessment (Praxos 741, 2008), ten deep groundwater exploration boreholes were drilled to depths ranging from 150 m to 198 m. The highest blow yield recorded was 30 L/s with major water strike at 148 m and has a potential long-term yield of 5 L/s. The combined potential long-term yield was estimated at 11.5 L/s for a 24-hour pump cycle. Borehole water quality ranges between Class 0 and Class 3. High nitrate levels in top aquifers may have contaminated deep-seated borehole water quality and therefore some deep borehole may seem to have moderately high nitrate levels.

Continuous water level and temperature monitoring indicate definite differences between deep water strikes and shallow water strikes. Two permanent data loggers were installed in ELW 2 and 5 and are used to gather long-term time-series groundwater level and temperature fluctuations.

An additional exploration odex borehole (ELW 15) was drilled into the old Hernic quarry (OHQ) and was tested at ±25 L/s with a maximum recorded water level drawdown during the step tests of 0.05 m. The borehole can be used as an emergency abstraction point in the quarry.

Concept description of "man-made" aquifers within the platinum/chrome sector

Platinum and chrome mines, as gold and coal mines, have for many years altered the hydrogeological and hydrological flows of the aquifers and catchments to create anthropogenic or "man-made" conditions. Primary to surface flows are the destruction of the subsoil conditions, especially drainage channels with often much higher permeability after mining. During rainfall events this results in higher recharge into the subsoil and aquifers.

Aquifer conditions also changed substantially. Pre-mining, most of the aquifers were semi-confined aquifers with low effective porosities (10—5), compared to the now backfilled open pits consisting mostly of fresh norite and anorthosite gravel and boulders with effective porosities of up to 25%. The pits are up to 60 mbgl whereas the natural groundwater levels may range from 15 to 20 mbgl. As a result, groundwater is continuously discharged from the semi-confined to the unconfined systems. Mining activities by default lead to enhanced recharge conditions and further to this large primary aquifers were created which stores large volumes of water. The platinum sector therefore are unknowingly already involved with AR and needs to develop site-specific strategies to manage it more effectively Linked to this is a delicate salt balance and with mostly inert rocks, only natural cycles e.g. nitrates need to be managed, with no or limited acid rock drainage expected.

Man-made aquifers at EPM

The Mine gets its raw water from the eastern channel of the Hartbees Irrigation Board (HIB) channel and stores it in the OHQ which serves as a water storage dam. The OHQ consists of an old open pit 40 m deep which is partially filled to a depth of 28 mbgl and then filled with water till roughly 21 mbgl. The quarry material consisted of waste rock form the open pit, basically anorthosite and norite. The OHQ is divided by a dolerite dyke to form a western and eastern portion and modeled as W_Qry and E_Qry (Figure 1). During the groundwater exploration phase, an exploration ODEX borehole (ELW 15) was drilled into a backfilled portion on the western side of the OHQ. Prior to the AR project water was then pumped from the OHQ via a floating barge fitted with four pumps to a water treatment plant where it is cleaned for both potable and process water use.

The obvious advantages are that the natural rock filter lowers source water turbidity significantly. Lower turbidity results in lower operational costs; for example, longer periods between filter replacements, less chemicals required and less pressure on activated carbon cells. ELW 15 measured some12 m below barge pump intake and able to access water from the quarry for a longer periods; for example, in case of a major canal breakdown much more storage is accessed by using deeper borehole water. Water in storage went up from an approximate 80 000 m^3 to 330 000m^3 and with variable availability of irrigation water the simulation model showed the Mine to run for 160 days without make-up water, whereas with only the barge it can run for some 39 days without make-up water.

Water quality and specifically nitrates were a bit of a concern, initial measurements for ELW 15 were measured at 18.2mg/L, similar to the regional groundwater measurements and close to the allowable domestic water limit of 20 mg/L (Class 1 limit is 10mg/L, Class 2 is 20mg/L). However, storage of water and evaporation in the OHQ creates a salt sink and over time the backfilled portion would become more saline over time which might result in the OHQ not been suitable for a storage facility. The boreholes however provide the Mine with the flexibility to dewater the OHQ and dill it with low TDS and low nitrate source water. Further to this, if the nitrate level is too high within

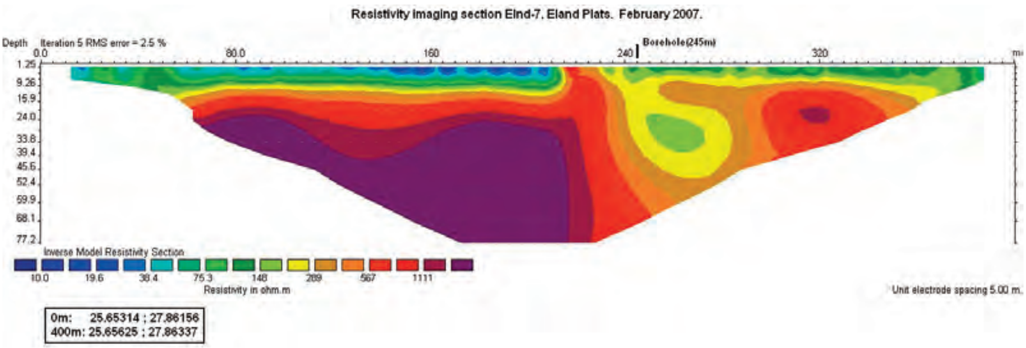

Figure 2 *Geophysical profile 7, shows where high-wall ends and boreholes was positioned.*

the OHQ, then the cannal water can be used directly within the water treatment plant.

At the OHQ the topography dips slightly towards the west and water flows from east to west. The western portion of the OHQ is already rehabilitated and there was enough space available to develop additional boreholes. As a result the western portion of the OHQ was selected to develop a new well-field. Astersat images where used to identify where the backfilled portion of the OHQ is situated. Once the position was established a series of multi-resistivity profiling were done to identify where the high-wall ends and where the deepest part of the OHQ is (Figure 2). Based on the results, six sites were selected and drilled.

Boreholes were developed within the backfill material using an ODEX drill-and-drive method. Boreholes were drilled six meters into the quarry floor using the normal air-percussion drilling method. All ODEX sections have steel casings with inside diameters of 194 mm and the air percussion sections have inside diameters of 165 mm. ELW 16 and ELW 17 were drilled to confirm results from the geophysics and ELW 18 to ELW 21 were drilled as production boreholes with recommended yields of between 19.5 and 28 L/s.

All boreholes were tested for macro elements. All boreholes are elevated in Total Dissolved Solids (TDS), Electric Conductivity (EC), Magnesium (Mg) and Nitrogen (N) values and are classified as Class 3, except ELW 15 having much lower TDS values. This might be as a result of water intercepted by ELW 18 -21, being more stagnant, whereas ELW 15 is located 10 m from the OHQ and therefore much closer to the recently recharged surface water.

The boreholes were equipped with submersible pumps and connected with a separate pipeline to the process water tank at the WTP. ELW 15 was connected to the potable water line and supplies water to the potable water line within the WTP.

One of the major concerns was water loses from the OHQ to the surrounding aquifers. This is constantly checked by measuring input and abstraction volumes and also comparing water level data of two monitoring boreholes within the insitu aquifer next to OHQ. The boreholes are within 50 m from the quarry and both the boreholes show stable water levels some 6 m above the quarry water levels. Leakage into the aquifer is unlikely and it is more likely for the aquifer to decant into the quarry. Further to this, the volumetric measurements over a period of 15 months show some 30 000 m^3 more water abstracted from the OHQ compared to water pumped into the quarry. Some of this water might be attributed to rainfall and runoff water, but a potion might be attributed to the aquifer slightly decanting into the OHQ. Personal communication with the previous owners suggest that the there was water in the aquifer and limited decanting took place from the aquifer.

On-site weekly data is taken to check water quality, critical are the nitrate values. The source water nitrate values range from 8 to 15 mg/L and the borehole water continued to have nitrate values between 10 and 30 mg/L. The stagnant water in the quarry and the waste rock could be the source of the higher salt load. Therefore to remove stagnant water and to flash the system from excess salts the quarry was dewatered to levels below the backfilled area. During both dewatering attempts the EC and nitrate levels showed significant increase and correlates well with periods when no water was pumped into the quarry. After the final dewatering event and the quarry was filled again the water quality from the boreholes showed significant improvement with nitrate levels below 10 mg/L and EC values below 60 mS/m. Since early 2011 the quarry was kept at the same level, with salt levels not increasing and since April 2011 the nitrate levels have also become more stable (Figure 3).

Tharisa Minerals

Tharisa Minerals (TM) is some 40 km west of EPM. The Mine has no raw water source and new raw

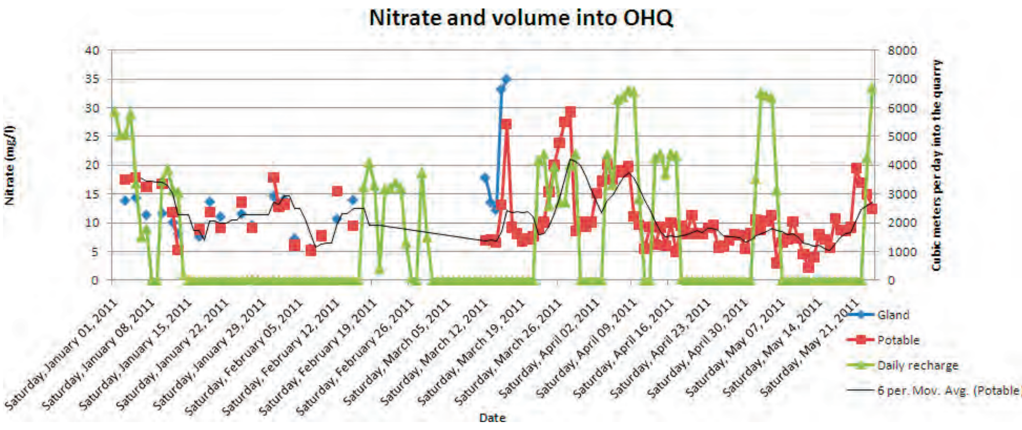

Figure 3 *Recharge versus nitrate in OHQ at EPM*

water sources are only available late 2014. The Mine therefore had no choice than to use local water sources. In the first couple of years of development the Mine was lucky with high rainfall events and water harvested in the open pit was enough to maintain the operations. In the first two years of operation TM only produced chrome concentrate. However in the course of 2011 TM will be running a 100 kiloton per month platinum/chrome circuit and as a result requires more water. In the past, Hernic also mined on the site and again an old existing backfilled open cast pit was established and rehabilitated. In this case, r it seems as if the open pit intercepted a substantial upper aquifer and the aquifer discharges into the old open pit and then into river system. The water management plan was to intercept and harvest from the pit and use the water as process water. As a result, limited water is spilled into the receiving environment.

Three symetrics boreholes were drilled between 28 and 36 meters below ground level (mbgl). The boreholes showed blow yields of more than 20 L/s (Figure 4) and from experience gained from EPMthe boreholes were not formally tested (sentence construction confusing?). Only quality data was taken and the boreholes had an excellent quality with very low TDS, TSS as well as nitrates. It was not only suitable for process water, but the broader spectrum of elements showed that it was suitable for potable water. This may be as a result of the more weathered soil like conditions and as a result it may be that in the anaerobic subsoil nitrate might have been oxidized to NOx. This however still needs to be reviewed in the years to come.

Conclusions

Both case studies show that it is possible to store water within old mining works within the Platinum mining areas in South Africa. EPM mine is now operating for more than three years and both quantity as well as quality data suggest that it is a viable option. The open pit at TM shows promising results and it seems as the resource will become the sole supplier of water to TM.

Figure 4 *At TM the drilling showed clearly more brown weathered material.*

These two examples are small compared to the existing backfilled mines available within the area and probably represent only 0.5 to 1% of the available backfilled mines within the western platinum belt. Some 2 billion cubic meters of material were already mined and the porosity of the backfill material is estimated at 30%. As a result of the blasting and breaking of the material the effective porosity is close to the porosity then the water available from the drainable pore spaces can be estimated at 25%. This makes the amount of water in storage in the western limb as much as 500 Mm^3. From this some back filled mines continually leaks into underground workings, where clear water is mixed with dirty water and at huge costs pumped from depth and disposed as dirty water, containing hydrocarbons, high suspended solids and nitrates in excess of 100 mg/L. Even if current water in storage has elevated nitrates, it can still be used as process water and gland service water and lift the heavy burden carried by potable water supplies

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