Transforming Groundwater from Risk Management to Asset Management in the Mining Sector, South Africa

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Abstract
The mining sector in South Africa is growing rapidly and requires large volumes of water and existing bulk water infrastructure were planned for agricultural and domestic requirements. Furthermore, continued environmental pressure from government and public forums require mining houses to continue to improve their environmental management practices. Xstrata Eland Platinum therefore decided to optimize their available groundwater resources and developed an Integrated Groundwater Resource Management Plan (IGRMP). The aim is to introduce groundwater as a sustainable partner, rather than a risk. During Phase I hydrogeologist and mining geologist worked together and proofed the value of an integrated approach. The IGRMP clearly shows Xstrata Eland Platinum's commitment to continue to improve the manner on how they deal with our rapidly diminishing water resources.

Key words: sustainable, integrated, neotectonic, deep groundwater, South Africa

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 area is covered with mining developments and stretch over a distance of 80 km. To date most new mining developments receive their raw water from existing water resources, and as a result water security is becoming one of the major concerns for sustainable mining developments. Climate variability also contributes to water insecurity and calls for new innovative water resource development and management strategies.

The Department of Water Affairs and Forestry (DWAF) 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.

General geology
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.

Method of investigation
Mineral geologists investigate ore bodies through a series of core and air percussion boreholes and therefore most of the hydrogeological data required for hydrogeologists are available. Improved hydrogeological understanding can be gained by adapting mineral resource exploration data, and thereby collating hydrogeological information. Data typically include core losses, water losses, water strike, yields, rest water levels, etc. At Eland Platinum all the core data is available and was used in collaboration with traditional groundwater exploration methods to site new groundwater boreholes.

Using core data, water exploration boreholes were placed at positions where geological conditions are known and to depths where possible water strikes were expected.

Review of existing groundwater specialist report

The groundwater specialist investigation was conducted by Africa Geo-Environmental Services (Pty) Ltd (AGES) and results thereof were incorporated as part of the EMPR (AGES, 2006). As part of this study the findings from the specialist investigation was used as the point of departure and some of the significant findings were reiterated in this report.

Hydrogeological conditions

The upper soil zones consist of a black to grey clay or "turf" layer, becoming red-brown at depth (5 m). Weathered quartzite forming loamy sandy soil, occurs closest to the drainage lines, resulting from eroded quartzite in the upper portion of the catchment. The upper soil zone forms a rainfall dependent perched aquifer with a thickness between 1-5 m and blow yields less than 0.1 L/s.

The weathered and fracture zone consisting of gabbro, norite and anorthosite, overlain by colluvium, together from 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.

Fault zones in the weathered/fractured rock formations form preferential flow pathways and may form fracture rock aquifers, having a variable spatial distribution (AGES referred to it as secondary fault zone aquifers). According to Vegter (1995a), 40% of boreholes drilled into the gabbro have blow yields less than 1 L/s.

Water quality

Groundwater qualities associated with boreholes within Mothutlung and on farms where fertiliser-intensive agriculture is practiced are poor (Elandsfontein 440 JQ). Poor water quality results 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 domestic water supply is 2400 mg/L.

Numerical modeling results

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 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/d 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/d.

Comments

During the specialist groundwater investigation no boreholes were drilled deeper than 65 mbgl and transmissivity (T) value of 2 m^2/d were used during numerical modeling. This resulted in an expected maximum inflow into the under ground mining works of 11, 8 L/s. If the T-value is higher than estimated, then the inflow can be much higher and it may have substantial influence on the existing conceptual hydrogeological model.

Assess existing geological exploration data

Geological geological core data was reviewed and core boreholes with high fracture densities and where core losses were identified at depth, were identified as possibly indicating high permeable zones. An aero-magnetic survey was done for the mining area and manipulated to capture possible geological structures, for example dolerite dykes. Two distinct dyke strike directions were identified, *viz.* dykes shown to have the highest magnetic susceptibility strike at ±320º and dykes shown to have a lower magnetic susceptibility strike at ±295º. After closer inspection in the open pit, the ±295º striking dykes seems to contain both lamprophyre and dolerite material and was labeled as lamprophyre dykes.

Geological structures

The maximum compressive stress (σ_1) migrated from striking NNW-SSE to the current stress field (Zoback et al., 1992) striking WNW-ESE with a NNE-SSW directed extension strain (σ_3). Such a directed stress field would close any NNE to NE-striking structures. NW-striking faults are perpendicular to extension strain direction (σ_3) and are expected to be open.

The major geological events were linked to historical tectonic stress fields and shown in. The first stress field orientation where σ_1 strike NNW-SSE (4A) can be linked with fault plane strike directions of the Brits Graben. The second orientation where σ_1 strike NW-SE (4B) can be linked with major dolerite dykes striking ±320º and the third orientation where σ_1 strikes WNW-ESE (4C) was linked to the lamprophyre dykes. This supports the sequence of events with the Brits Graben, followed by the dolerite dyke intrusions and finally the lamprophyre intrusions.

Magnetic data also show lateral displacement of the dolerite dykes at ±80º, but no lateral displacement on the lamprophyre dykes, and supports the theory that the lamprophyre dykes have intruded much later that the dolerite dykes. The WNW-striking features create prominent geomorphology landforms. From a hydrogeological perspective the neotectonic activity, where maximum strain occurs, are expected to be open and should act as hydrologic conduits. The lamprophyre dykes show similar strikes and may have intruded into the neotectonic strain direction. As a result the lamprophyre dykes should act as vertical hydraulic conduits and were identified as possible groundwater exploration targets.

Thermal collapse was greatest in the centre of the BIC, and as a result the BIC sagged towards the centre. At Eland Platinum Mine UG2 reef data indicates the BIC to dip towards the north at ±18º and the strike of strata E-W. Inward collapse of the BIC and subsequent bending of the BIC should have induced lateral stress that will have the tendency to push the top part of the BIC away from the centre. The mineralised zones (UG, MG and LG) form distinct layering in the BIC, and can also act as weak zones where stress release can take place. This may have resulted in over-faulting or thrust faulting of top layers over bottom layers. Geological exposures in open pit mines show relative movement of top layers over the bottom layer, most significant is that trusting is evident in the roll-stone and turf layers.

Drilling

Based on prevailing geological conditions and geophysical results ten groundwater exploration boreholes were selected. Six of the ten exploration boreholes had measured blow yields higher than 2 L/s and water strikes were recorded at 140 mbgl. Three additional boreholes were rehabilitated and one existing borehole was re-drilled. An additional odex borehole was drilled into the old Hernic quarry.

Borehole Tests

Five exploration boreholes were selected for long-term yield tests and three permanent pressure transducer water level monitors (divers) where installed and two divers were rotated for each borehole yield test.

The constant discharge rates of ELW 6, 7 and 8 were all more than 5 L/s and ELW 6 and 7 had T-late values greater than 10 m^2/d. Yield tests confirmed water strikes deeper than 60 mbgl at ELW 1, 6 and 8. Yield tests also confirmed ELW 4 to have a water strike at ±25 mbgl and ELW 7 at about ±55 mbgl. The combined potential yield is estimated at 11.5 L/s

Borehole water quality

ELW 1, 4, 7, 8 and 15 plot within the bicarbonate hydrochemical cation facies and suggest recent rainfall recharge. ELW 6 does not plot in a specific anion facies but is elevated in chloride and suggest much older water or more evolved water (Freeze *et al*, 1979). ELW 8 is depleted in calcium and magnesium and plot within a different anion facies.

Samples show low to moderately high nitrate levels, ranging from 2.2 to 28.8 mg/L. The top aquifer show high nitrate levels (AGES, 2006), most likely as a result of continuous commercial crop framing (nitrification). High nitrate levels at boreholes with deep water strikes are probable due to contamination from the top aquifer. Significant results from the long-term monitoring are:

- Data from ELW 6 show a 24-hour water level cycle. This may be as a result of gravity forces resulting from the sun and the moon, having a marginal stress and strain effect on the rock mass and may therefore be detected in fractured rock aquifer water levels. Temperature data show a similar pattern.
- Temperature results clearly show ELW 2 and ELW 9 to have different temperature signatures. Therefore confirming different geothermal gradients and therefore different flow paths and it may indicate different recharge areas (Freeze *et al*, 1979)

Conclusions

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 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.

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