Challenges of Open Pit Dewatering for an Intrusive Ore Body

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Abstract ERM was appointed to design, implement and manage an Open Pit dewatering programme in the Mpumalanga province of South Africa. The mining development comprises the northwest-southeast trending tube-shaped ultramafic to mafic rocks of the Uitkomst Complex (length of 9km), hosting Ni-Cu-Cr-Co-PGM mineralization. The Uitkomst complex intruded the basal units of the westward dipping Transvaal Sequence, which is underlain by the Archaean Granite. Mean annual precipitation for the area is 1,000mm with recharge ranging between 1.3% (of Mean Annual Precipitation) for the Uitkomst Complex and the surrounding mountain ridges and 7% (of MAP) for the fault zones. Previous hydrogeological investigations estimated high groundwater inflow volumes into the open pit areas. Of particular concern was the potential high mine inflow rates along fault zones in the open pits and the ability to dewater these high yielding zones. A phased approach, using numerical flow modelling, followed by field validation has been used to refine the mine dewatering programme. In-pit, as well as out-of-pit dewatering has been simulated for the different mining stages to estimate mine inflow volumes and to determine the best dewatering solution. During each phase of the project additional dewatering wells have been installed and the models continuously refined.

Key Words Open pit dewatering, fractured aquifer, high groundwater inflow

Introduction

The mine started off as an underground mining operation and has been in production since 1996. In 1997 the mine started investigating the expansion of their underground operation to include the mining of nickel, and other Platinum Group Minerals (PGM's) from opencast pits. The ore is processed on site to form sulphide concentrates of nickel, copper, cobalt, platinum, palladium, rhodium and gold. Pit 1 has been mined out in 2009 as it delivered only a shallow ore body of small dimensions. Pit 2 (maximum depth of 70m – 1255m amsl) will be mined out towards the end of 2010 and was the main focus of the initial dewatering programme (Phase I and II borehole installation). Pit 3 (maximum depth of 300m- 1180m amsl) has a life expectancy of 18 years with ore excavation scheduled to start in 2010.

A phased approach was undertaken to investigate the dewatering requirements. During the Phase I intrusive investigations across the mining area, aquifer characteristics and parameters were determined. A conceptual and numerical flow model has been formulated to simulate the optimum dewatering scenarios for the open cast mining operation. Based on the results of the Phase I investigation, the scope of work for Phase II has been defined, which included the implementation of the mine dewatering plan. This included the installation of dewatering boreholes across the Pit 2 and 3 mining areas, dewatering management and refinement of the numerical model. Based on the results the mine dewatering strategy, its design and management was refined.

During the Phase 3 borehole installation more focus has been placed on refining the Pit 3 dewatering programme and updating the groundwater model. Electronic data logging hardware have been installed at all dewatering boreholes to assist with daily management of the dewatering performance for each borehole. Data are being uploaded to an internet web-site to allow for remote data analysis and hardware control.

Methodology

Intrusive investigations

Based on the conclusions of the Phase I investigation, a dewatering plan was formulated, which included the positioning dewatering boreholes at potential high yielding zones, areas were data gaps in the conceptual model existed, and areas where no information was available.

Phase 2 included a comprehensive intrusive field investigation, which included a detailed geophysical investigation of the area to delineate drilling targets and high yielding zones. Magnetic, time domain- and frequency domain electro-magnetic methods were used to identify structures that provide preferential groundwater flow and inflow, as well as the profiling of these with depth to obtain the water strike depths and orientation, angle of dip, and the width of the structure. The geophysical investigation was one of the first challenges faced on site. Execution of the electromagnetic based geophysical methods and interpretation of the data have been complicated by the high conductive nature of the ore body, combined with intrusive diabase sills and near surface clay.

Drilling commenced in three separate phases with Phase I (2008) incorporating 16 dewatering boreholes, Phase II (2009) a further 18 boreholes and Phase III (2010) another 20 boreholes. Borehole depths range between 60 and 125m. All boreholes are 204mm (ID) percussion drilled boreholes, with solid steel casing installed over the full length of the borehole. Slotted casing was installed over all water bearing zones. Aquifer tests were performed to quantify aquifer parameters and to determine dewatering pumping rates.

Numerical modelling

A numerical groundwater flow model, using MODFLOW was constructed to simulate the groundwater flow through the area and to evaluate the optimal dewatering scenarios. The model was calibrated with observed water level data, covering approximately 7 years. The challenge has been that no long term time-series data were available with most data collected during exploration drilling programmes and the feasibility study. A 99% correlation between the calculated and observed groundwater levels was reached, with a variance of $28m^2$. Taking into consideration the steep topography in sections of the study area this was considered to be adequate.

Two different dewatering scenarios were simulated, namely in-pit and out-of-pit dewatering. During the in-pit dewatering scenario dewatering occurs only from a sump within the pit void area, while in the out-of-pit borehole dewatering scenario, dewatering boreholes outside the active workings were incorporated into the dewatering program.

Hydrogeology

A total of fifty (54) boreholes were drilled and constructed to date. This includes twenty-two (22) dewatering production boreholes and 32 monitoring boreholes, all positioned around the Pit 2 and 3 mining area. The drilling programme identified a number of high yielding groundwater zones (Table 1).

Most groundwater strikes occur between 10 and 60m below ground level. It is defined as the main aquifer zone and represents a secondary confined aquifer. Very few water strikes occur deeper than 60m. Results from the aquifer tests show a wide range of transmissivities ranging from < 1 to $1{,}100m^2$/day. The majority of groundwater flow occurs along these high transmissivity fault zones and it dominates groundwater flow.

Based on evidence collected during the drilling program it can be said that the confined to semi-confined aquifers that occur in the area are associated with the weathered and fractured rocks. There is little to no evidence that the upper purely inter-granular aquifer (associated with weathering 20 to 30m deep) yield high volumes of water.

The average depth to rest groundwater level is 23m. The vast majority (73%) of boreholes indicate a depth to groundwater of between 10 and 30m.

The groundwater flow direction in the vicinity of Pit 2 is towards the west and northwest and at Pit 3 towards the southeast, all towards the Adit Stream bisecting the two pit areas. Groundwater flow gradients to the east of the Adit Stream (Pit 2 area) are in the order of 1:12 and towards the west (Pit 3 area) the gradient is about 1:30.

Table 1 *High Yielding Groundwater Zones*

Zone	Pit	Water Yield	Transmissivity
• Northwest-southeast trending Pit 3 shear zone	3	Between 1,300 and $2{,}600m^3$/day	$1{,}100m^2$/day
• North-eastern contact zone with the Transvaal rocks	3	Between $1{,}700m^3$/day and $2{,}600m^3$/day	$1{,}100m^2$/day
• Northwest-southeast trending Pit 2 fault zone	2	Between 345 and $600m^3$/day	$80m^2$/day
• Adit Stream fault	2 and 3	Exceeding $2{,}600m^3$/day	$1{,}100m^2$/day

Hydrochemistry

Groundwater on site is classified as Ca-Mg-HCO_3 type and most groundwater quality results are indicative of recently recharged groundwater (low Cl content). The natural dominance of Mg (and the low Na+K concentration) in the groundwater is typically of (ultra) mafic rocks.

Groundwater from boreholes located around Pit 2 and 3 have a low total dissolved solids (TDS) content compared to the Department of Water Affairs Standards and with reference to "Point G" located in the Gladdespruit, downstream from the mining area. Groundwater is of excellent quality and is currently discharged into the surface water network. This is one of the major challenges for the mine in that a tailings storage facility is also located within this valley and upstream from Pit 2. Discharged groundwater quality is monitored on a regular basis to ensure that contaminated groundwater is not discharged into the environment.

Numerical modelling of groundwater dewatering

Two different dewatering scenarios were simulated, namely in-pit and out-of-pit dewatering. During the in-pit dewatering scenario, dewatering occurs only from a sump within the pit void area, while in the out-of-pit borehole dewatering scenario, dewatering boreholes outside the active workings were incorporated into the dewatering program.

In-pit dewatering is seen as a proactive dewatering approach that reduces in-pit groundwater inflow risk and improves pit stability. Calculated daily groundwater inflow is 1,560m^3/day for Pit 2 and 6,380m^3/day for Pit 3 (highest between years 3 and year 9, when high yielding structures are intersected; where after it decreases to below 3,000m^3/day in year 10 as dewatering of the main weathered - fractured aquifer take place). Annual in-pit dewatering volumes for Pit 2 and 3 vary from 0.17 to 0.56Mm^3/a, and 0.16 to 2.32Mm^3/a respectively. Daily dewatering at Pit 2 is expected to be less than that of Pit 3. Most inflow is likely from the NW-SE Pit 2 fault, with the highest inflow occurring in year 1. The model calculates a decrease in groundwater inflow for years 3 and 4 as aquifer dewatering take place.

Combination of In-Pit and out-of-pit borehole dewatering has the advantage that it reduces the risk of in-pit water contamination. The reduction of "dirty" water is important in terms of the mine water management plan. The high yielding fracture zones require that borehole dewatering has to commence at least 6 months prior to the commencement of mining (late 2008/early 2009) and has to continue to the end of life of mine (2027/2028).

A total of 22 dewatering boreholes have been installed as part out-of-pit borehole dewatering system. The efficiency of some of these boreholes is likely to decrease due to the intersection of the cone of depressions of adjacent dewatering boreholes, as well as in-pit dewatering.

The simulated efficiency of out-of-pit dewatering or percentage reduction of in-pit groundwater inflow varies between 60 and 85%.

Limitations and Risks

Final commissioning of the Phase I dewatering boreholes and implementation of a continuous pumping regime only commenced during February 2009. This left a dewatering deficit of 12 months.

The following limitations in terms of the dewatering assessment and potential associated risks are noted:

Data management

Large areas of the open pit area are inaccessible for the installation of dewatering boreholes and characterisation of preferential pathways. This limited the installation of out-of-pit dewatering boreholes at preferred localities to intercept excess groundwater inflow.

Secondary aquifers have a complex drawdown response to abstraction due to aquifer boundaries and regular monitoring and abstraction adjustments have been implemented to refine the dewatering plan.

A dedicated hydrogeologist is required on site to manage the open pit dewatering. This proved to be full time task including management of the operation and maintenance of all equipment, managing discharge and water quality and reporting to and collaboration with different sections of the mine.

Groundwater dewatering simulation

Pre-excavation dewatering might take a few months to obtain the required level of drawdown required to minimize in-pit groundwater inflow. The numerical model was initially constructed and calibrated based on data from a limited number of hydrogeological boreholes and therefore requires continual refinement, calibration and validation as monitoring information becomes available due to the highly heterogeneous nature of secondary aquifers.

Inflow into pits 2 and 3 identified possible data gaps in the conceptual and numerical groundwater models.

Preferential Flow paths

The north-eastern and south western boundaries of Pit 3 has been identified as a high inflow, high risk areas. The north-eastern boundary corresponds to both the Pit 3 footprint boundary as well as the Uitkomst intrusion boundary and is characterised by high groundwater flow through a highly weathered and fractured zone. Water movement along this zone poses a high-wall stability risk.

Design

Pit 2 and 3 is separated by a perennial stream. Even though this stream is underlain by rich ore reserves the mine is prohibited by national law to mine through this area. This leaves a weathered high wall traversed by a flowing stream, in-between the two open pits and has its associated stability and water inflow risks.

Continues updating of the numerical groundwater is required to ensure effective open pit dewatering.

References

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