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Groundwater & Mining: Slope Stability, Flooding, Dewatering and Disposal

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Mining impacts on the ambient groundwater environment in two ways: the resource and the quality. The groundwater levels are usually lowered by the mining operations and the ambient hydrochemistry is altered by exposure of the ore to oxygen. The impacts can also be divided into short medium and long term. Hydrogeological and hydrochemical studies enable these impacts to be identified prior to mining and incorporated into the mine plans in order to minimise the magnitude of the impact. In the South African groundwater environment, prevention is better and cheaper than cure, because of the difficulty of remediation.

A number of mines have closed and these impacts are being experienced today. On closure groundwater levels rebound which result in a number or impacts. These impacts relate to decant and migration of poor quality of water into the hydrological environment.

One of the most difficult things to predict on mine closure is the impact on the ambient hydrology.

This intern leads to difficulties in budgeting for mine closure.

ABSTRACT

The world increase in the coal price has led to an expansion in coal mining in South Africa. Coal mines impact on the ambient groundwater environment by altering the groundwater flow and the groundwater quality. The prediction of the impacts prior to mining and on closure of a mine is fundamental in determining the environmental impact of any mining operation. Collection of field data and development of mathematical groundwater flow and transport models to simulate the potential impact, aid in the assessment of the pre and post mining environmental impact. This also aids in the development of a monitoring system to quantify the impacts and to assess the effectiveness of the environmental management programme. This data is required for decision makers and awarding of mining authorisation.

INTRODUCTION

The increase in coal price has led to a boom in activities in the coal mining industry in South Africa. Numerous new and reopening of old coal mines has led to heightened awareness of the potential environmental impacts of coal mines. The Department of Mineral Resources has developed a system of Environmental Management Programme Reports (EMPR) to meet the environmental requirements and directives under the Minerals Act No. 50 of 1991 and its regulations. One of the requirements of the EMPR is an assessment of the impact of mining on the groundwater environment.

The development of mathematical groundwater models based and calibrated on field data has enabled hydrogeologists to simulate the natural groundwater environment and quantify the impacts prior to mining and at mine closure.

With the aid of the mathematical flow models groundwater flow patterns and solute transport patterns can be simulated as a productive tool in determining the environmental impact of a proposed coal mine. The mathematical flow model allows ambient flow patterns to be simulated. Taking the proposed mine plan into consideration, the groundwater inflow into a mine, dewatering volumes, zone of influence (radius of drawdown) and rebound of water levels after mining operations stops, can be simulated.

Construction of a groundwater contaminant transport model in conjunction with groundwater flow models has enabled hydrogeologists to predict likely impacts of mining operations on the hydrochemistry. Developments with regard to acid base accounting allow for an indication of the potential for acid mine drainage generation. However additional research is needed into reaction rates due to changes in pH inside the aquifer and likely geochemical reactions between contaminants and the natural environment.

The paper is divided into a number of sections each addressing different scenarios where mathematical modelling can aid in the prediction of hydrogeological impacts of coal mines. This technology can be transferred to any mining operation.

<u>Table 1 – Hydrogeological Impacts of Mining</u>

Groundwater

Required data to determine potential impacts of mining.

FLOW: Operational Phase	QUALITY: Operational Phase
• Inflow Volumes • Radius of Dewatering Cone • Rate of Groundwater Movement • Daylighting / Decanting	• Contaminant Movement • Acid/Base Accounting Indication of Starting Concentration • Contribution from Waste Dumps
FLOW: Closure	**QUALITY: Closure**
• Rebound of Water Levels • Decanting • Daylighting • Rate of Movement	• Movement of Contaminants • Dilution, Dispersion and Geochemical Reactions • Daylighting and Water Quality • Predicted Concentrations, Volumes and Loading

<u>Construction of Groundwater Flow Models</u>

The construction of groundwater flow models is critical to the effectiveness of the model's capability of predicting the impacts of mining on groundwater. Numerous software packages are available but the most applicable is a package capable of simulating both flow and solute transport.

The model grid must represent the mine and all potential impacts. For this reason, the model grid should represent the catchment of the mining area to ensure that groundwater/surface water interaction can be determined.

Calibration of the model is done on field data obtained from aquifer tests and from measured groundwater levels. Average calculated values for transmissivity and the storage coefficient are used during simulations. The impact of variations in these parameters is best achieved by means of a sensitivity analysis, in most cases, not enough data is available to conduct statistical/stochastic modelling to obtain the confidence levels for modelling results. The results from sensitivity analysis enable the hydrogeologist to provide an indication of so called worst case scenarios, e. g. the impact of flow along fractures on dewatering volumes or travel time to surface water bodies.

Additional data required to assist in the construction of the model are geology, topography, groundwater quality, groundwater flow patterns and the proposed mine plan and mining rate.

<u>The Use of a Groundwater Model in Prediction of the Mine Impact of Mining on the Groundwater Flow Environment</u>

The calibrated groundwater model can be used to predict significant impacts of mining during the construction, operational and closure of the mine, on groundwater flow patterns.

Inflow Volumes: Taking into consideration the natural groundwater flow environment and the mine plan it is possible to calculate the volumes of inflow into the mine. Simulated water balances are used to estimate the rate of groundwater inflow into the mining area. The inflow volumes may vary as the mine progresses and it is possible to evaluate the volumes at different time periods and mining rates with time.

The size of the pollution control dam, volumes of make-up water required for the plants and additional information for the water management system, may be derived from volumes obtained from the water balance simulations.

i) **Drawdown Cone**

Dewatering due to the mining operations results in a drawdown cone imposed on ambient groundwater levels and thus on inflow of groundwater into the mine. The determination of the extent of the drawdown cone or radius of influence around the mine is critical in establishing the impact of the mine on surrounding groundwater users, surface water bodies or interaction with surrounding mines. The predicted maximum zone of influence can also be calculated.

The imposed dewatering cone has the advantage of controlling contamination movement away from the mine but the disadvantage of drawing contamination into the mine workings from surrounding areas.

ii) **Rate of Movement**

The normal rate of movement of groundwater is dependent on the permeability and porosity of the aquifer and the groundwater flow gradient. Natural flow rates are altered in the mining areas due to the change in groundwater flow gradient. Dewatering results in the steepening of the gradient towards the working. Discard dumps, slimes dams and storm water control dams form a groundwater mound and accelerate movement away from the mine.

iii) **Rebound of Water Levels**

The rate of rebound of water levels are critical in determining where the mine is likely to flood and the time period before environmental problems are likely to arise. For example, if it will take 25 years for water levels to rebound to initial conditions after mine closure, it is likely to take the same period before contamination migrates away from the underground workings, or for water to daylight or decant at the adit or lowest part of the open pit.

As a result, prediction of the rise in water (rebound) level is critical in determining the time span before the full magnitude of the impact on the groundwater will manifest itself. This is critical for decision makers in determining time frames for mine closure.

The Use of a Groundwater Flow Models in Prediction of the Mine Impact of Mining on the Groundwater Quality

Due to the nature of coal deposits in South Africa and the presence of pyrite, the majority of South African Coal mines have the potential to generate acid-mine drainage.

The forecasting of the potential of a mine to generate acid mine drainage is very complex. The most widely used method to determine the acid generating potential of the geological formations within the void and backfilled material, is acid-base accounting. The potential movement of acid mine drainage and resulting contamination of the ambient groundwater resources, daylighting and the impact on surface water resources, is critical in assessment of the environmental impact assessment of a potential coal mine or a mine closure.

i) Acid/Base Accounting

Acid/Base accounting is a method whereby representative samples of the different lithological units to be disturbed by the mine operation are taken for laboratory testing. The laboratory tests determine the acid potential and base potential of the samples to determine if the lithological unit has the potential to generate acid mine drainage. The testing is usually completed for two situations. The first is the immediate water soluble acid-base potential and the second, the acid base potential after complete oxidation. The results usually give the best and worst case scenarios and the actual potential is somewhere between. Typical acid base accounting results are shown in Table 2 for a Witbank area coal mine.

ii) Contaminant Movement

The contaminant or solute transport model uses the groundwater flow model as a basis. Contaminant transport models are able to predict expected concentrations of contaminants and rate of movement of contaminant plumes.

It is difficult to establish the initial concentration of the simulated contaminant inside the mining area.

The results from the fully weathered acid/base accounting cannot be used as a representative starting value for contaminant transport simulations since the results would be an over estimation of reality. These results would rather provide guidance in the selection of the contaminant to be simulated and the chosen initial concentration thereof. The value for starting concentration of the simulated pollutant can be obtained from water analyses from other old mines in the same coal field, preferably from the same coal seam. Previous investigations for the application for mine closures provided the opportunity to drill into old coal mining voids. Indications are that sulphate concentrations, for example, in water taken from old voids can be as high as 5000mg/l. This kind of information is unfortunately not available during the field investigations for EMPR's. The most appropriate solution in this case, if no information from other old coal mines in the coal field is available, is to conduct a sensitivity analysis incorporating a worst case scenario approach. The contaminant transport model must be updated with field data, as mining progresses, so that as the decommissioning phase is approached, the groundwater quality monitoring sections of the EMPR document can be revised with the aid of the contaminant transport model.

The second complexity in contaminant transport modelling are the geochemical reactions that take place between the contaminant plume, the rock mass and the natural groundwater due mainly to changes in pH conditions. These are subject to in-house research at present.

The resulting contaminant transport models at present being used by the authors are natural dispersion, advection and dilution models. These together with the results of the acid/base accounting represent the worst case scenarios and give an indication of the order of magnitude of impact rather than an absolute answer.

The time period for contamination to leave the mine and the relatively slow movement of the plume in the aquifer make decision making with regard to granting of mining authorization for the State Departments difficult. The results generated by the groundwater flow model and solute transport models aid in the decision making by quantifying the potential impact.

In summary, the solute transport models are able to predict rate of movement and concentration of contaminant plumes at crucial positions in the aquifer and in addition allow for the quantification of loads on surface water bodies by calculation of volumes and concentrations of contaminated groundwater daylighting along the river, in streams or at springs.

iii) **Monitoring Systems**

If potential environmental impact is quantified, a monitoring system can then be developed in order to monitor the impact.

The models developed during the study for a specific case can be used to design the monitoring programme of existing observation boreholes. This involves both the monitoring positions and sampling intervals. The models can further point out areas where additional monitoring may be necessary and thus assist in designing additional drilling positions.

CONCLUSION

The prediction of the impacts of potential mines or the impact of post mine closure conditions on groundwater poses a major problem assessing the environmental impacts to obtain the granting of mining authorisation or closure.

Groundwater flow and solute transport models enable risks to be identified and quantified and as a result presents data on which management decisions can be made.

Groundwater flow models also aid in the design of the layout of the mining area, water management and the establishment of a monitoring network.

The starting or initial concentrations of the potential contaminant plume are difficult to be calculated because of the lack of information during the early stages of the investigation. This problem may be overcome by looking at the sensitivity of the aquifer to large changes in initial concentrations provided that the model is updated through the life time of the mine, as more information becomes available.

Contaminant transport models are, however, the best tool available to provide predictions in terms of groundwater quality and loading during the preparation of the EMPR document.