Aquifer Rebound Investigation at a Defunct Coal Colliery in South Africa

P. J. H. Lourens[1], P. D. Vermeulen[1], A. Allwright[1]

[1]*Institute for Groundwater Studies, University of the Free State, PO Box 339, Bloemfontein, 9300, South Africa*

Abstract

The Institute for Groundwater Studies at the University of the Free State has been appointed to investigate the aquifer/aquifers response at a defunct coal colliery in South Africa. The investigation was required to determine possible risks to the natural aquifer systems to enable to the mining company to obtain a mine-closing certificate. A numerical groundwater model was developed using the FEFLOW software package. The pre-mining conditions suggests that the seepage areas along the tributary draining the area was naturally susceptible for seepage conditions and mine water discharge will occur if a pathway exits.

Keywords: Aquifer Rebound, Defunct Mine, Numerical Model, Seepage, Monitoring

Introduction

The Institute for Groundwater Studies at the University of the Free State has been appointed to investigate the aquifer/aquifers response at a defunct coal colliery in South Africa. The colliery includes three subsections, the Main Underground Operation, the Strip Mine Operation and the Secondary Underground Operation (Figure 1). All mining operations ceased in 2005 and rehabilitation of the Strip Mine Operation have been completed. The investigation was required to determine possible risks to the natural aquifer systems to enable to the mining company to obtain a mine-closing certificate.

Hydrogeological and Hydrolgical Regimes

The local groundwater regime within the minining rights area comprises the following hydrstratigarphic subdivisions:

I. The **shallow (weathered) groundwater regime** associated with Quaternary deposits of the Karoo Supergroup i.e. alluvium, colluvium and weathered Karoo rocks.
II. The **intermediate (fractured) groundwater regime** associated with hard fractured Karoo rocks i.e. sandstone and dolerite of the Karoo Supergroup.
III. The **deep groundwater regime** associated with pre-Karoo rocks i.e. karst aquifer comprised of dolomitic rocks of the Transvaal Supergroup.
IV. The **unnatural groundwater regime** (mine groundwater regime) – resulted from mining and has changed the hydrodynamics of the coal mined areas.
V. The **ashfill groundwater regime** (artificial) associated with the filling of fly-ash within the Colliery's defunct mining areas (See Figure 1for Ashfilled areas).

The mining rights area is drained by two non-perrenial streams and their tributaries. The non-perrenial streams joins the main river draining the area north of the defunct mining operations (Figure 1).

Topography and Rainfall

The topography ranges between 1500 and 1421 mamsl, sloping towards the north. The annual mean rainfall is approximately 599 mm (last 25 years), mainly occuring in the summer season in the form of thunderstorms.

Methods

To evaluate and create a conceptual understanding of the study area, all available historical groundwater monitoring data was converted into a format that is compatible with the WISH software package. After evaluation of the historical data, down-the-hole chemical profiling was conducted on existing monitoring boreholes, using an YSI-Multi-parameter probe, to determine if there

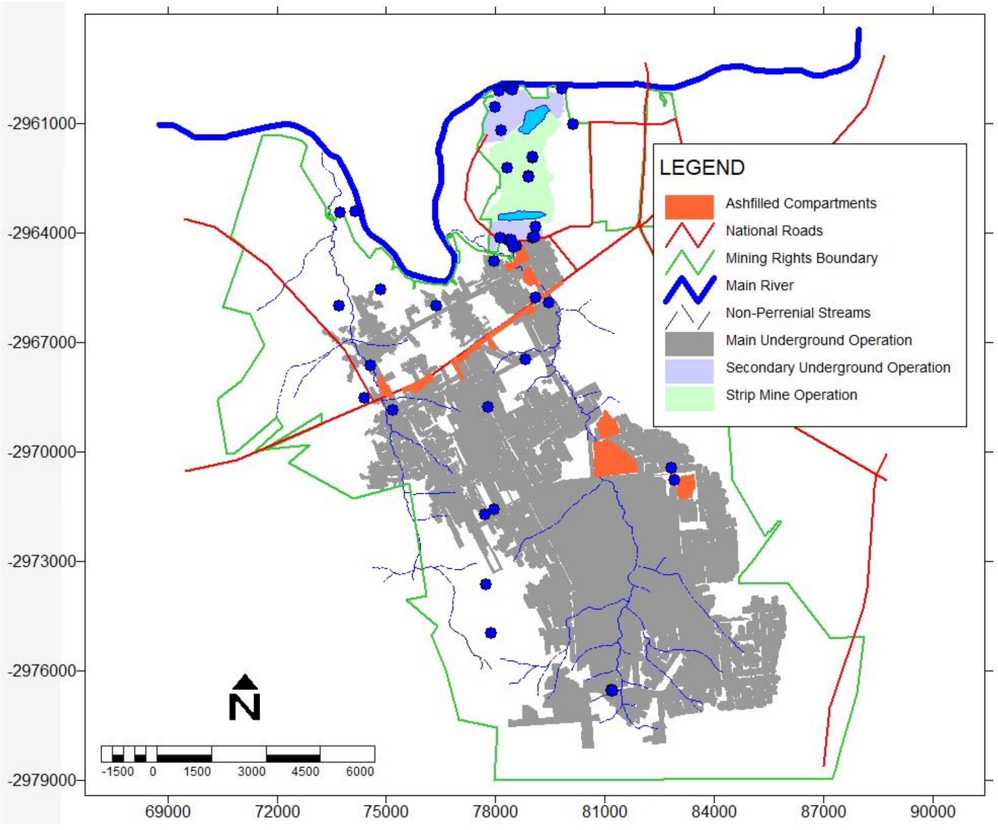

Figure 1 *Site Layout map – blue circles represent borehole locations*

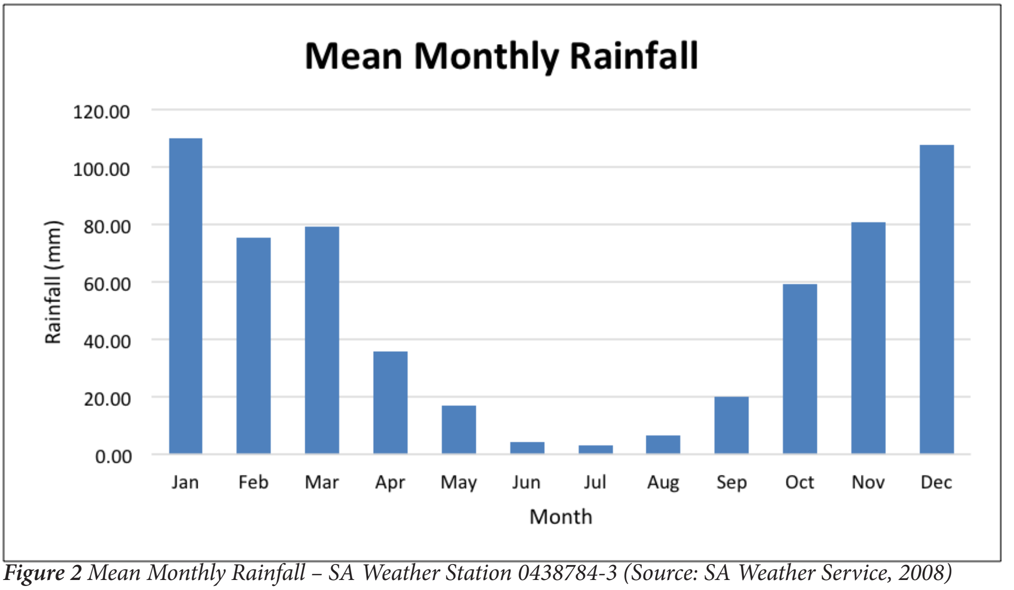

Figure 2 *Mean Monthly Rainfall – SA Weather Station 0438784-3 (Source: SA Weather Service, 2008)*

is any physical or chemical stratification in the aquifers. A numerical groundwater model was developed using the FEFLOW software package. FEFLOW uses the Finite Element Method in its modelling calculations (Wasy, 2004). The model was developed in a staged manner, initially a steady state pre-mining model was created to analyse the groundwater flow before mining took place. Building on this, a steady state model for mining conditions to analyse the groundwater flow in response to mining influences. The model for mining conditions simulates the current groundwater equilibrium and was calibrated with the latest water levels. After steady state model calibration, various scenarios was considered to assess groundwater conditions at the colliery.

Results and Discussion

The extensive groundwater level monitoring data indicates that the mining voids of the underground operations are completely filled with water (Figure 3). The volumes of water in the mine voids came from various sources which include recharge from rainfall, overlying aquifers and the underlying dolomitic aquifer system. The water levels of the shallow and intermediate groundwater regime have recovered since mining ceased (Figure 4) and the mine voids left to be flooded. that the natural groundwater level has recovered to its natural state before mining commenced.

The water quality of the groundwater regimes have a great variability within each regime (Figure 5). The water types for the shallow groundwater regime varies between Na-HCO_3 and Na-Mg-HCO_3 types. The water types for the intermediate groundwater regime varies between Na-HCO_3, Ca Mg HCO_3 and Ca-Cl types. The water types of the deep groundwater regime varies between Na-HCO_3 and Ca-Mg-HCO_3 types. The water types of the mine groundwater regime varies between Na HCO_3, Ca Mg-HCO_3, Ca-SO_4 and Na-SO_4 types. The water types of the ashfill groundwater regime varies between Na-HCO_3, Ca-Mg-HCO_3 and Na-SO_4 types.

The groundwater regimes all indicates a sodium enrichment. Sodium enrichment is typically related to waste water discharge, dewatering of deep mines or natural

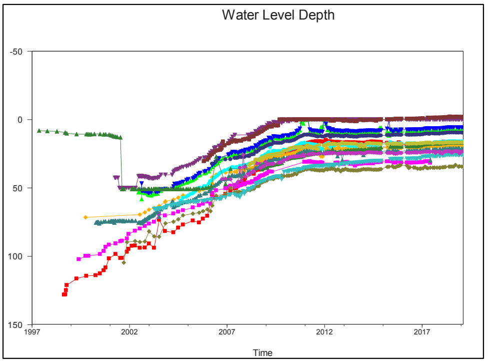

Figure 3 *Water level time graph of the mine groundwater regime*

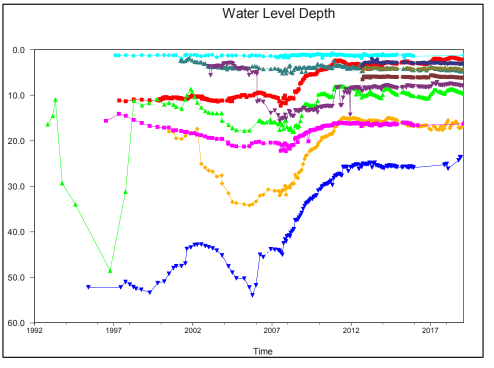

Figure 4 *Water level time graph of the shallow and intermediate groundwater regimes*

deterioration of the groundwater quality by ion exchange within a aquifer (Figure 6). Therefor the Na-HCO_3 type samples can indicate an influence from the underlying coal mine, or longer resisdence times could cause the sodium enrichment (Figure 7). However, the low sulphate concentrations of the shallow, intermediate and deep groundwater regimes provide evidence for the natural deterioration of the groundwater quality, whereas the sodium and sulphate enrichment in the mine and ashfill groundwater regimes are related to the underground coal mining and ashfilling conducted, respectively.

Down-the-hole chemical profiling was conducted at 31 boreholes and the results are summarized as follows:

I. No stratification is evident in the shallow, deep and ashfill groundwater regimes.
II. Of the six intermediate boreholes profiled, one borehole to the south indicates stratification.
III. Of the 14 mine boreholes profiled, three

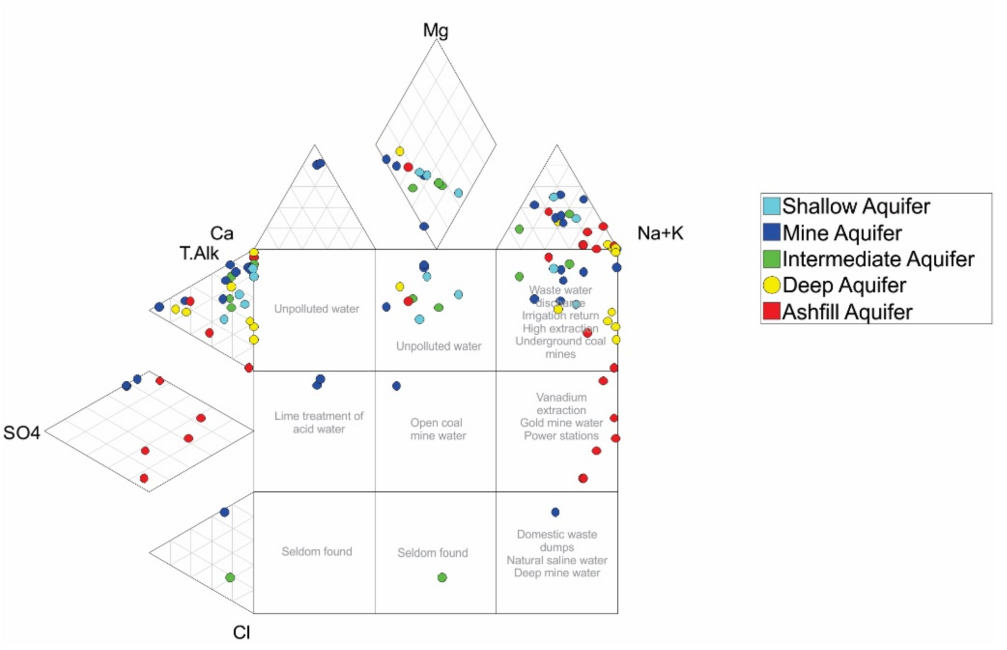

Figure 5 *Piper diagram plot of the water qualities of all the groundwater regimes*

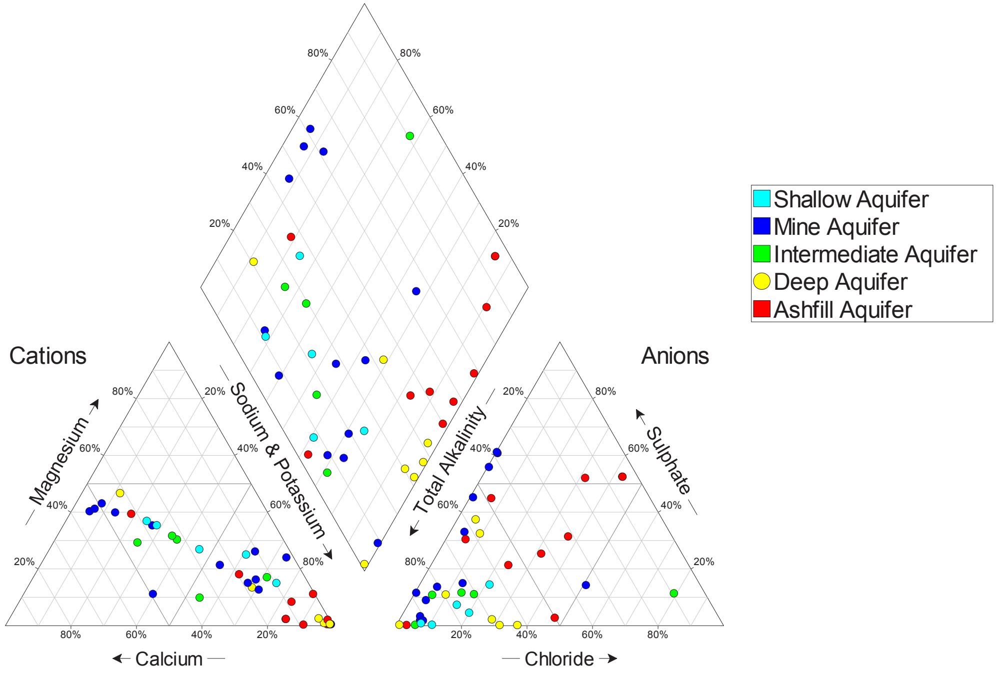

Figure 6 *Expanded Durov diagram plot of the water qualities of all the groundwater regimes*

show signs of stratification (one to the south and two to the north).

The southern-most Main Underground Operations was first to fill up, and the longer flooded period and distance from the upward groundwater flow are most likely the reason for stratification at the southern most boreholes. The majority of non-stratified boreholes indicates that mixing of water between the mine and upper aquifers is taking place.

Above zero pressurised areas, or rather where the groundwater level intersects the surface, simulated by the pre-mining model (i.e. no mining voids and dewatering) are found along the eastern non-perrenial stream. Therefore suggesting that the current discharge area was naturally susceptible for seepage conditions, but the appearance of mine water at the ground surface would only occur if a pathway existed The model shows the discharge area was naturally susceptible for seepage conditions. This hypothesis advocates that mine water was going to discharge in this area (if a pathway existed), regardless of ash backfilling in the mining voids.

The numerical mining model was used to to used for different scenarios to analyse the current and most important groundwater flow processes and influences:

I. Scenario 1 considered the contribution to the groundwater system from the underlying Pre-Karoo dolomites, which was found to be variable between areas where groundwater is moving from the underlying dolomites into the mine voids, and other areas where groundwater is moving from the mine voids into the underlying dolomite.
II. Scenario 2 incorporated subsidence into the mine model to simulate the effect of ground surface subsidence on the groundwater flow system, by increasing the hydraulic conductivity and recharge in these areas. The subsidence areas increased the recharge to the groundwater system, and potentially aids the upward flow at the current discharge areas.
III. Scenario 3 incorporated the ash-backfilling of the mining voids at Main Underground Operations to investigate the effects on the groundwater system. The incomplete ash-backfill scenario, 50% of mine height within current ash-backfill areas, was found to form a combination of the two extreme cases (complete and no ash-backfilling), where the velocities within the mine void are partially retarded by the ash-backfill, and downward flow from the mine void in the northern limits is more prominent than in the no ash-backfill scenario, yet not as dominant as in the complete ash-backfill scenario. These simulations lead to the formation of a hypothesis where completing the ash-backfilling could potentially reduce the current discharge volumes.
IV. Scenario 4 incorporated a fault into the opencast mine area to more realistically represent the groundwater system within the Strip Mine Operation. The southern final void (active water abstraction) was analysed with the numerical groundwater model and it was found that groundwater flows into the void from the south, west and east; and flows out from the void along the northern border. Considering the four additional modelled scenarios without abstraction and the fact that the measured levels in the northern final have maintained a lower water level over an extended time period, the maintained water level in the southern final void could be lifted for a trial period to observe the groundwater system response.

The Australian Groundwater Modelling Guidelines established by Barnett, et al. (2012) were utilised to define the confidence-level of a model, where Class 1 is a low confidence model, and Class 3 is a high confidence model. These criteria for model confidence were analysed, and an overall model confidence of Class 2, medium confidence, was decided for the developed numerical groundwater model for the Sigma area.

Conclusions

All the underground workings are completely flooded and mixing of water between the mine and upper aquifers is taking place. According to the water level data, it is plausible that the natural groundwater level has recovered to its natural state before mining commenced. The pre-mining conditions suggests that the seepage areas along the tributary draining

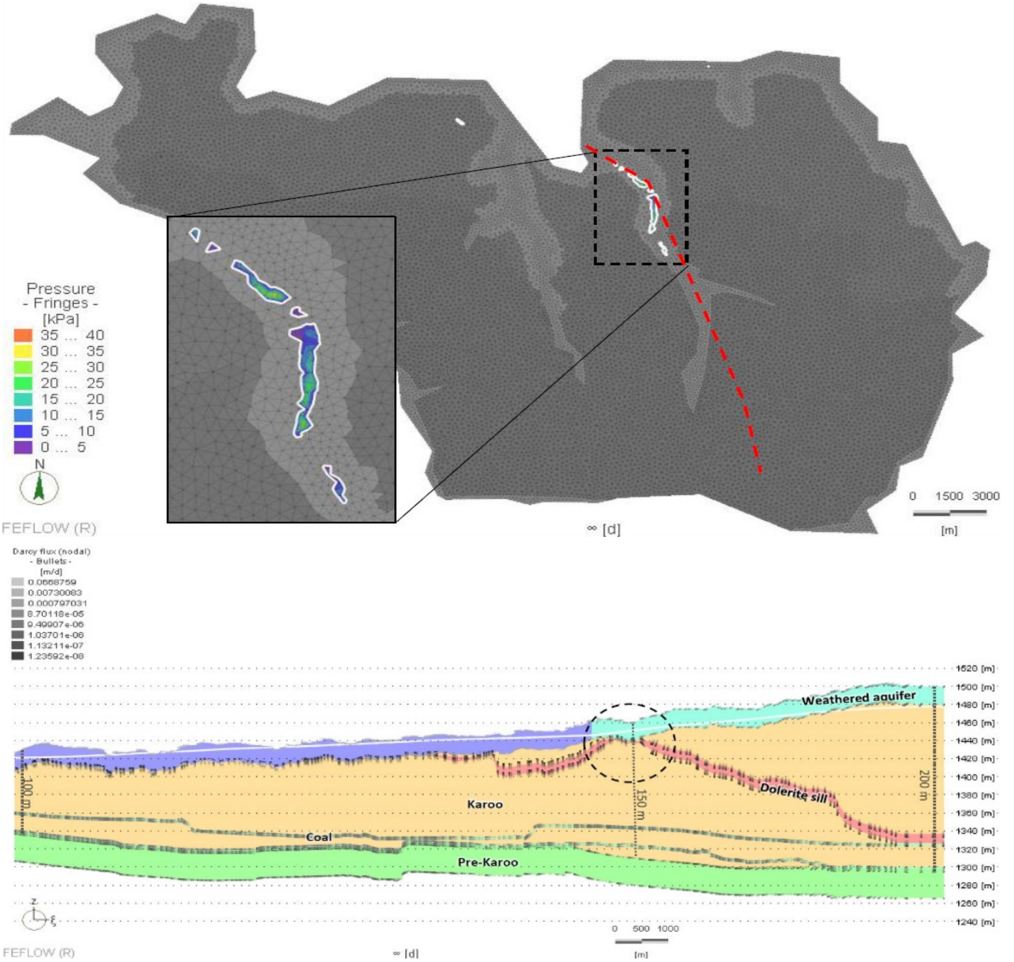

Figure 7 *Over pressurised areas within the pre-minind numerical model (plan view-top) – red dashed line indicates the cross-sectional line of the cross-section*

the area was naturally susceptible for seepage conditions and mine water discharge will occur if a pathway exits. Therefore, regardless of the ash-backfilling (coal power station ash-slurry) of the underground mine voids, seepage would have still occurred at these areas, however, ash-backfilling could potentially reduce the current discharge volumes, if the right methodology is followed. The risk of suspending active pumping from the southern final void for a monitoring period is low, as long as the level in the northern final void remains stable.

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