Groundwater Modelling in Support of Post-Closure Acid Mine Drainage and Treatment Planning - Case Study

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Abstract

As coal mines close and active dewatering ceases it is likely that most of them will decant over time. This is a major concern in South Africa as the post-closure decant water is often at a low pH and of poor quality. These older coal mines often thus pollute aquifers and rivers with little chance of dilution in the relatively dry interior of the country.

Groundwater modelling was conducted by Digby Wells Environmental on a defunct coal mine that operated between mid 1950's and early 1990's. Mining had been conducted using open pit and underground methods. The mine has been decanting since 2004. The objective of the groundwater modelling was to assess the current groundwater status and predict future acid mine drainage (AMD) decant rates and qualities to be able to properly plan for post closure management and treatment at least cost. The mine is currently decanting at 3.2 ML/d but the prediction is that this could range between 1 and 6 ML/d depending on rainfall conditions and possible subsidence. The decant quality is also variable based on the volume of the flooded mine void as well as the interconnectivity between the open pits and the underground void. The pH of the flooded mine void is neutral as long as more than 95% is under water. The pH is lowered to 3.4 if the water seeps through the pits via interconnecting tunnels. The ideal abstraction point for the AMD treatment was one which was accessible, allowed for least flow of water through the workings, allowed for maximum flooding of the workings whilst still allowing for a buffer in case of heavy water ingress and one which allowed the best quality water to be abstracted. The depth of the pump was determined considering the chemical stratification of the borehole water.

The groundwater modelling was effective in predicting if and where new decants could occur and the expected AMD quality. Passive treatment using constructed wetlands would help mitigate the AMD but will not be sufficient due to the decant volume and site geomorphological setting. Active treatment, such as a reverse osmosis, will be required to ensure that the in-stream water quality objectives are met. Further optimisation of the system to provide water to regional large scale consumers is possible. The use of vegetation to reduce groundwater ingression in some areas seemed to be an effective way of reducing contaminated water volumes.

Keywords: Decant, AMD, groundwater, coal mine

Introduction

Coal is the main energy resource of South Africa contributing to 77% of the energy needs (Department of Energy 2018) and is considerably higher than the 36% average internationally. In addition to its extensive use in the domestic economy, about 28% of the production is exported, making South Africa the fourth-largest coal exporting country in the world.

Coal is found in 19 coalfields in the country. The pertinent geological features controlling the occurrence and quality of the coal is site specific. A number of the coalfields are found in topographic highs, along watersheds. The seams in low-lying areas have been eroded by rivers and streams (Figure 1).

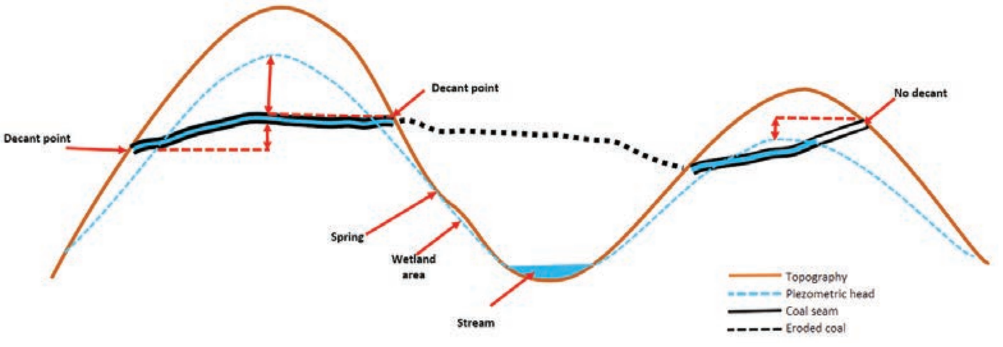

Figure 1: A conceptual model illustrating a coal seam and potential decant points

The steady state hydraulic head is often above the coal seam elevation. Due to this setting, these mines are likely to decant after closure. The decant takes place through shafts, boreholes, geological structures and/or weathered zones connecting the mine void with the topographic surface at an elevation that is lower than the hydraulic head. The decant is a serious environmental concern as it is often of poor quality and low in pH.

This paper looks into a decant investigation conducted at a coal mine in the KwaZulu-Natal. The mine was in operation between 1954 and 1992, and started decanting to the surface water streams in 2004. The objective of the study was therefore to assess the hydrogeochemical status quo and predict future trends in decant rates and qualities with the use of a conceptual and analytical models. The investigation outcome was then used to plan for post closure decant management and treatment at least cost.

The objective was also to define an optimum abstraction point and level to which the water in the working should be maintained to keep long term costs to a minimum and to prevent uncontrolled discharge.

Methods

The investigation was conducted following the review of existing reports, site visit, hydrocensus as well as conceptual and analytical modelling.

The colliery was an underground mine (Figure 2 and Figure 3) with a bord-and-pillar extraction method. Opencast mining was also performed to extend the life of the mine where the depth to the coal seam was less than 20 m below surface. A total of 12 boreholes were drilled for aquifer characterisation and groundwater monitoring. However, only three boreholes (BH2, BH2 and BH3) are included in this paper as they are deemed to be representative.

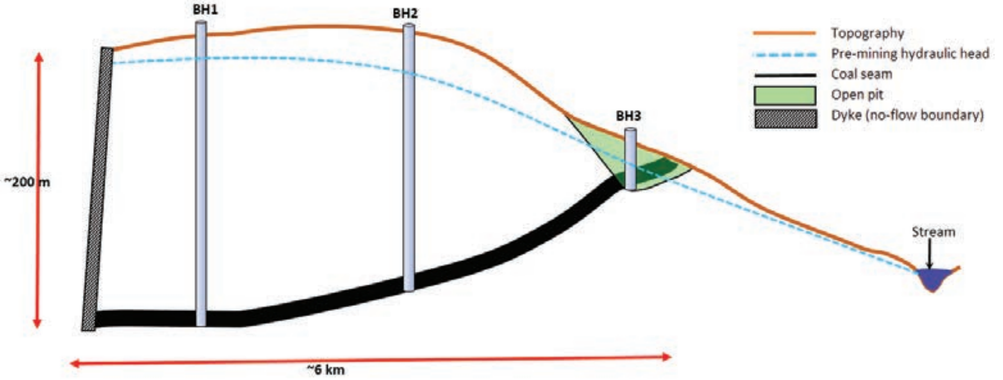

Figure 2: A simplified hydrogeological profile of the project site

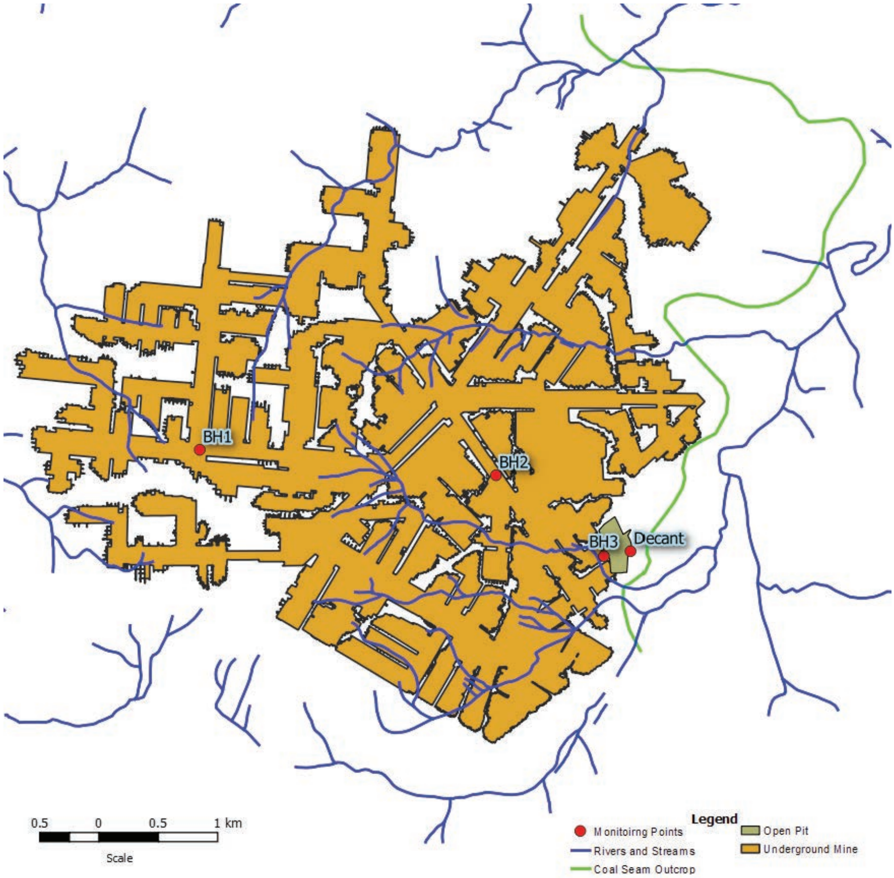

Figure 3: Site layout map

A stage curve (showing the capacity of the void to hold water at different elevations) was obtained from Hodgson (2006) and available mine plans. The maximum storage capacity of the mine void is 43.6×10^6 m^3, found at an elevation of 1194 meters above mean sea level (m amsl).

Discussion

Time-series water level of the monitoring boreholes is shown in Figure 5. By the time the mine closed in 1992, the water level was at 1160 m amsl. This elevation corresponds to a mine volume of 8.8×10^6 m^3 (Figure 4) and indicates that 20% of the void was already flooded. The water level rose steadily and reached to a maximum of 1190 m in 2004 where after decant started to take place from the open pit (Hodgson 2006, Vermeulen et al. 2011).

The decant is taking place at the intersection of the open pit and underground workings (Figure 5). Currently the water level in all of the boreholes intersecting the coal seam are at the same elevation (approximately 1190 m amsl), meaning that the voids are hydraulically connected.

Considering the amount of water that already existed in 1992, it took 12 years for the mine to flood. This translates into an average recharge rate of 4000 m^3/d, a conclusion also reached by Hodgson (2006). However, this is an average recharge and the influx into the mine void is seasonally controlled. The total amount could be as little as 1 ML/d in winter and as much as 6 ML/d after heavy rainfall periods. An average yearly value of approximately 3200 m^3/d is proposed for the mine.

The water quality can be classified into two distinct water types: those with pH around 7 (all boreholes intersecting the mine void including BH1 and BH2) and those with

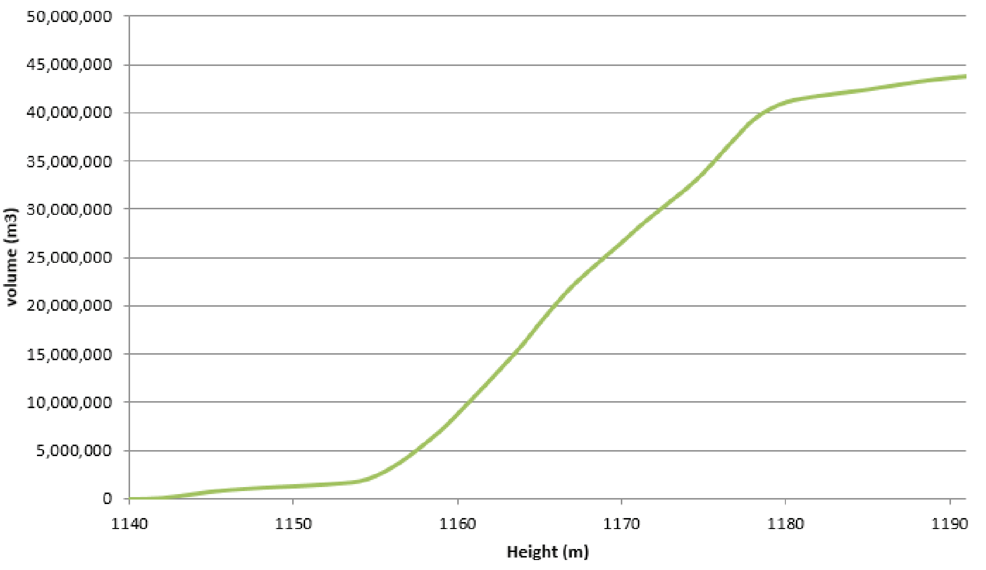

Figure 4: Stage curve of the underground workings

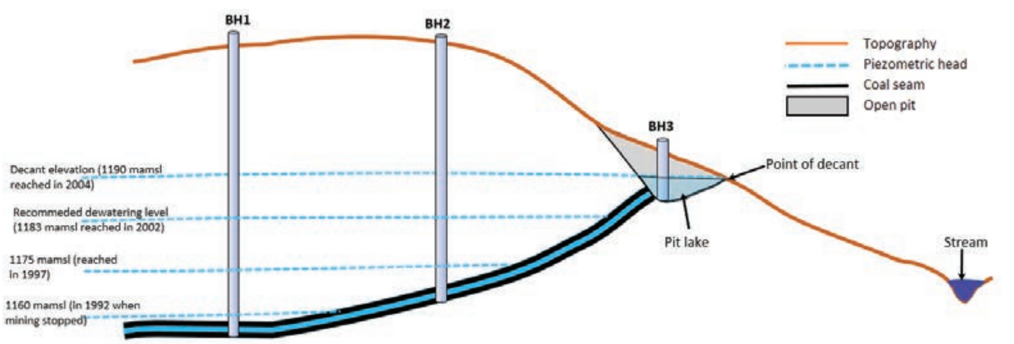

Figure 5: Mine-void flooding history and current decant elevation

Table 1: Mine water quality

Monitoring point	pH	EC	TDS	Cl	Alkalinity	SO4	Ca	Mg	Na	K	Fe	Mn	Al
BH1	7.8	44.3	267	8.8	243	0.92	32	18.3	53.7	2.6	0	0	0
BH2	7.4	50.4	323	22	202	54.2	49.4	15.4	41	15.9	0	0.05	0
BH3	3.5	548	4950	116	<2.48	3574	483	137	586	53.5	325	84.2	26.2
Decant	3.4	551	4912	120	<2.48	3561	453	138	584	53.1	317	81.6	25.9

Units are in mg/L, except for EC where it is in mS/m

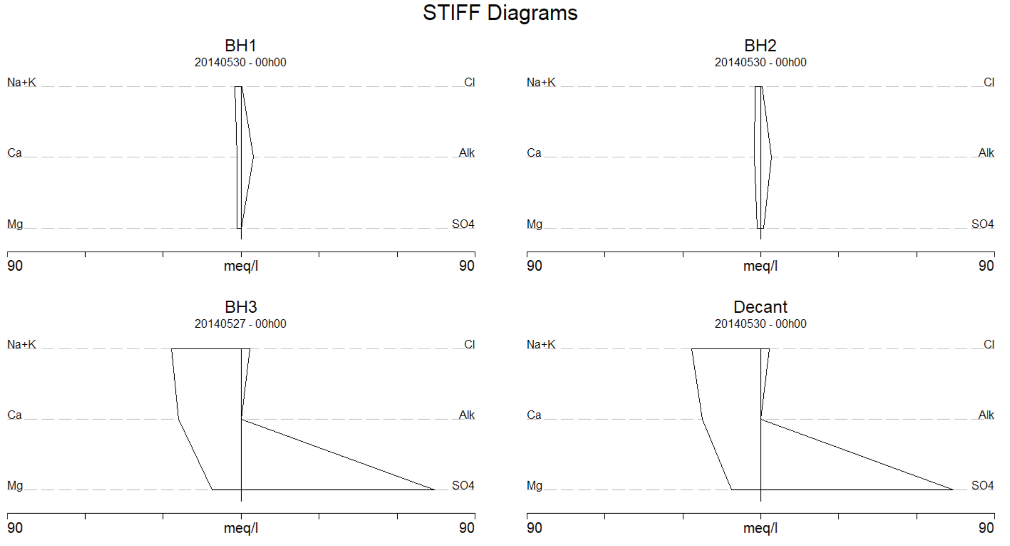

Figure 6: Stiff diagram of the mine water

a value of about 3.5 (borehole BH3 and the decant). The water chemistry is given in Table 1 and displayed in Figure 6.

The fact that the mine pH is around 6.5 indicates that calcium carbonate in the flooded mine voids buffers water from becoming acid. The flooding also minimises pyrite oxidation and hence acid generation.

Borehole BH3 is drilled in the backfilled pit where sufficient oxygen and water exists to generate acid. This borehole has very high sulphate values, together with a number of other elements such as Ca, Mg, Na, K, Al, Fe and Mn. Although the decant is originating from the mine void, it drains though the backfilled pit where the water is exposed to oxygen and the pyrite is oxidised. This results in the lowering of the decant pH, to the same level to the water in the backfilled pit.

Conclusion

Remediation through natural attenuation is not an option. Although the pyrite may eventually be completely oxidised, this is likely to take hundreds of years, if not more. However, there are many active and passive remediation techniques that could be applied based on the final quality objectives and the AMD geochemistry.

Sealing of the decanting point is another option to be considered. The hydrostatic pressure exerted by the decanting water is proportional to the hydraulic head above the decant point. The sealant applied should be able to withstand the hydrostatic pressure to form a reliable seal. However, the blocking of a decanting hole could force the water to daylight in areas that were not decanting previously and could possibly result in multiple decant zones.

In order to be discharged into the surface water regime and to meet the catchment management objectives, the preferred AMD management was pump and treat. Dewatering for the plant treatment is recommended to be directly from the underground workings to benefit from the alkaline nature of the groundwater. Passive treatment using constructed wetlands would help mitigate the AMD but will not be sufficient due to the decant volume, high proportion of monovalent ions and site geomorphological setting. Active treatment, such as a reverse osmosis, will be required to ensure that the in-stream water quality objectives are met. Further optimisation of the system to provide water to regional large scale consumers is possible. The use of vegetation to reduce groundwater ingression in some areas seemed to be an effective way of reducing contaminated water volumes.

Hodgson (2006) identified that a water elevation of 1188 m amsl has been insufficient to contain recharge during the rainfall seasons. Considering the average rainfall, lowering of the water level to approximately 1183 m amsl should be sufficient to buffer sudden increase of the decant rate that may be handled by the treatment plant. This elevation should provide for up to 2 years of water storage under average inflow conditions. At this elevation the mine will be flooded to 96% that will limit the space available for potential oxygenation and acid generation.

The volume of the mine void at 1183 m is approximately 41.9×10^6 m^3 (Figure 4). Considering the maximum void of $43.6x10^6$ m^3, the amount of water that needs to be pumped is 1.6×10^6 m^3. This is on top of the rainfall influx of 3200 m^3/d into the underground void. If the water level is to be lowered to the buffer elevation of 1183 m within a year, the pumping rate should be 7700 m^3/d. Thereafter, the rate could be reduced to the decant rate of 3200 m^3/d.

The ideal abstraction point for the AMD treatment was one which was accessible, allowed for least flow of water through the workings, allowed for maximum flooding of the working whilst still allowing for a buffer in case of heavy water ingress and one which allowed the best quality water to be abstracted. Treating better quality water at this site would save money due to reduced treatment costs and is possible to maintain this as the working get filled over a large area and not mainly from the outcrop area. Water flow is thus from the deeper levels to the shallow areas.

The mine water quality is stratified. The quality of the upper section of the boreholes intersecting the mine void is cleaner than the bottom section of the boreholes. The depth of the pump was determined considering the chemical stratification of the borehole water.

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