A case study of underground brine disposal

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Abstract

South Africa has a long history of mining and has limited natural water resources. This study assesses trial storage of by-product water treatment brine in a mined out coal mine compartment. Both bord and pillar and high extraction mining areas were investigated.

Borehole siting, drilling and testing indicated significant increases in porosity and permeability of the local fractured sandstone-siltstone aquifers over high extraction areas, consistent with published models of stress zones and rock failure over coal mine workings. Groundwater hydrochemistry and brine quality indicated that water in the compartment was a mixture of brine and shallow groundwater, indicating significant recharge through goafed areas.

Numerical simulations indicate long-term mixing/movement of salinity from the underground compartment. Zones of varying recharge over the mined out compartment result in head variations. Post-mining groundwater levels are expected to vary from pre-mining by as much as 10 m and may drive mixing and upward movement of brine contaminated groundwater. These high risk areas are confined to the immediate vicinity of high extraction mining.

Bord and pillar areas should be targeted for brine storage since stress fracturing and hydrogeological changes in the surrounding rocks are minimised.

Keywords: brine, storage, groundwater

Introduction

New Denmark Colliery (NDC) is located in the South African province of Mpumalanga near the town of Standerton. Significant groundwater inflow has resulted in excess mine water since shortly after mining commenced in 1982. The mine has coped with this problem through various methods, including a trial storage of brine in Compartment 321. To the best of our knowledge this has not been implemented at any other site in South Africa or internationally.

On average, the mine workings are located 200 m below ground level. The overburden above the coal seam comprises sandstone and siltstone of the Karoo Sequence. A series of dolerite intrusions are present at various depths in the overburden and also intersect the coal seam. A regionally extensive dolerite sill extends from near surface to a depth of 100 m or more.

Compartment 321 West was mined using bord-and-pillar methods. Longwall mining was used for Compartment 321 East. Surface subsidence and formation of goaf (rubble fill) is caused by longwalling when the coal seam that supports the overlying rock mass is removed and the immediate roof of the seam fails and collapses. Two areas of subsidence have been identified on surface above Compartment 321 East.

The objectives of this study were to assess the groundwater impacts of the trial storage of brine underground; and identify issues which may limit this method of brine storage, or which require further research.

Methods

An analysis of available information relevant to underground brine storage was conducted, including groundwater levels and water quality monitoring results. This was supplemented by field investigation, the development of a conceptual hydrogeological model, and numerical modelling of selected brine storage scenarios.

Field investigations

Six borehole clusters totalling 13 boreholes ("Golder boreholes") were completed in and around Compartment 321 (Table 1). Falling head test and slug test water level fluctuations were recorded with a Solinst Level logger 3001. Falling head test and slug test data were analysed using Aquifer Test (version 2.5). Results are presented in Table 1.

Table 1 *Borehole completion details.*

Borehole ID	Drilled depth (m)	Water strike depth(s) (m)	Blow yields (L/s)	Water level (mbgl)	Hydraulic conductivity (m/d)
GA03D	253	164	<0.1	115.02	4.7×10^{-5}
GA03S	57	47, 52	Seepage	16.5	5.88×10^{-3}
GA04M	118		Seepage	105.73	4.07×10^{-2}
GA04D	227		Seepage	203.97	8.9×10^{-1}
GA04S	55	dry	dry	38	4.78×10^{-4}
GA01D	254	232, 237	1.5	200	4.67×10^{-2}
GA06D	261		Seepage	171.74	
GA06M	129		Seepage	64.44	
GA02D	250		Seepage	83.95	5.31×10^{-5}
GA02S	47	31, 33, 43	0.6	11.7	1.18×10^{-2}
GA06S	57	32, 40	Seepage	27.1	
GA05S	58	dry	Seepage	dry	
GA05D	190	dry	Seepage	dry	
GA01S	22.5	dry	Seepage	dry	

Results

Groundwater levels from monitoring boreholes and boreholes drilled as part of this study are plotted in Figure 1. This shows groundwater dewatering in boreholes located in the immediate vicinity of high extraction mining ("goaf") areas.

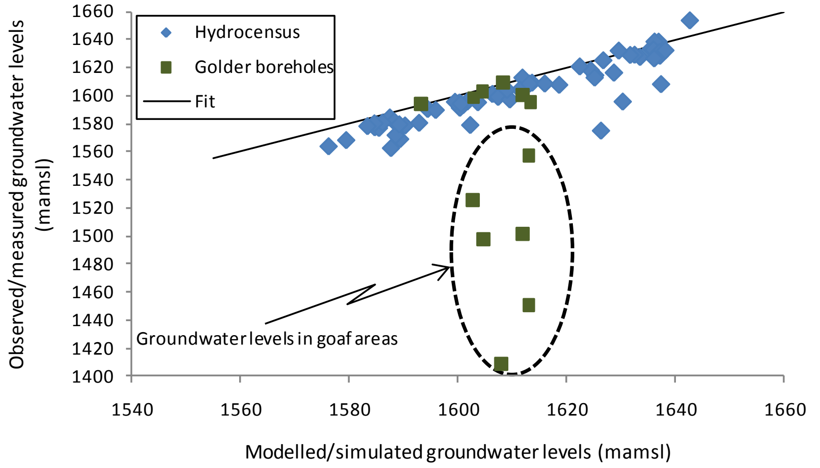

***Figure 1** Dewatering associated with high extraction mining above Compartment 321 East.*

Groundwater quality is summarised on the Piper plot in Figure 2. "B Brine" is the brine composition before pumped underground. Two modelled mixtures of B Brine and surface borehole C3 are plotted on the Piper plot in Figure 3. The samples from Compartment 321 plot between modelled 90% shallow groundwater-10% B Brine and 50% shallow groundwater-50% B Brine compositions.

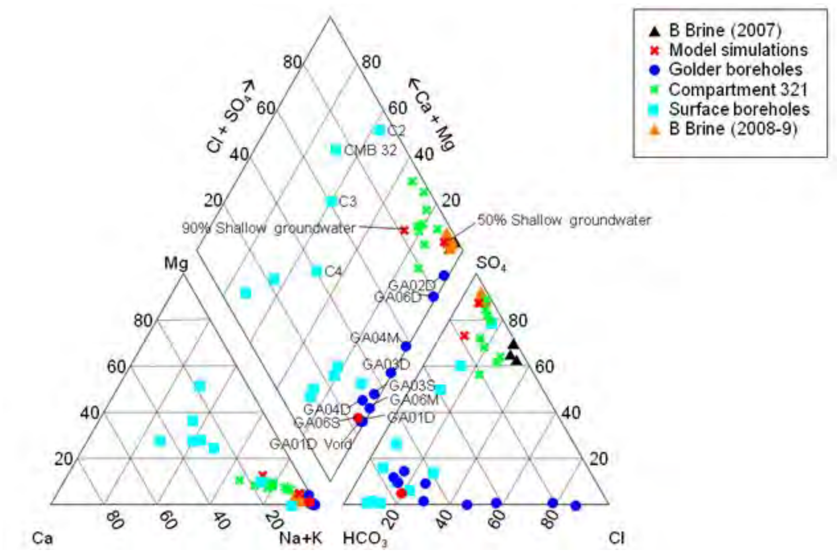

***Figure 2** Groundwater and brine quality associated with Compartment 321 East.*

Conceptual model

The groundwater system was conceptualised as comprising two aquifers:

Shallow aquifer above a regionally extensive dolerite sill. The sill is impermeable (where not affected by high extraction mining). The aquifer is localised and poorly developed with relatively low permeability (0.006 to 0.01 m/d). Recharge rates have been estimated at less than 1% to over 3% of annual rainfall (Hodgson 2001).

Deep aquifer below the dolerite sill. Associated with sandstone/siltstone and the unmined coal seam. Fractures in these units enhanced by mining will act as higher conductive zones and groundwater flow paths. This was observed in Borehole GA01D where fracturing below the sill due to mining subsidence produced high inflows. The deep aquifer is recharged from the shallow aquifer through fracture systems. The distribution of these systems is variable and drainage of water from the shallow aquifer into the deep aquifer is generally slow.

In undisturbed areas the deep aquifer is poorly developed with low permeability (5×10^{-5} m/d). However, above high abstraction mining areas, such as Compartment 321 East, the permeability is enhanced by several orders of magnitude.

- Numerical model simulations
- Numerical assessment was performed using the FEFLOW finite element numeric groundwater.

- The potential spread of brine-contaminated groundwater from Compartment 321 East was assessed assuming an initial Cl concentration in the brine of 1000 mg/L. The following scenario was assessed:
- Post-closure when the mine is fully flooded.
- Assumes a seal is installed at the level of the coal seam to retain brine in Compartment 321 East.

Model results indicated that the radius of dewatering around goaf areas may be as much as 400 m during mining. Post closure groundwater levels do not recover to pre-mining levels. Modelling indicates level changes by up to 10 m (Figure 3).

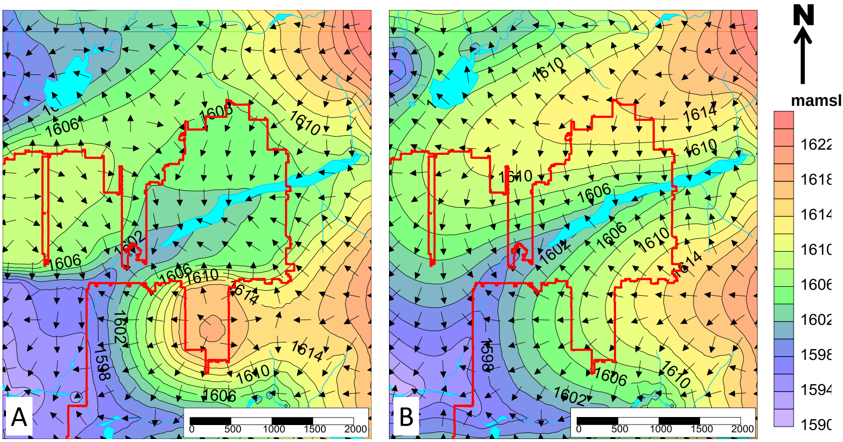

Figure 3 *Modelled changes in pre-mining groundwater level (A) relative to post-mining level (B). Scale bars indicate distance in metres.*

Discussion

The results of the field investigation are generally consistent with the conceptualisation of Fauconnier and Kersten 1982) (Figure 4). The water strike in borehole GA01D was encountered in a “large fracture” immediately below a local sill which may correspond to the “void” shown in Figure 4.

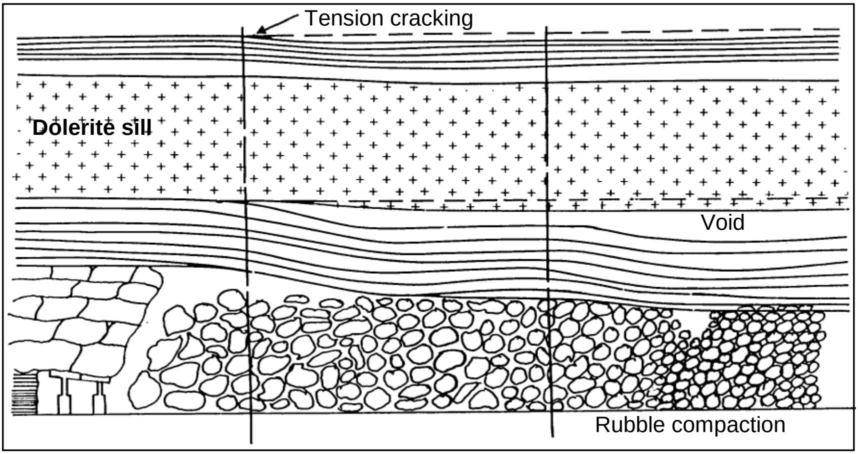

Figure 4 *Cross-section through a high extraction panel illustrating arrested subsidence by a dolerite sill. Note the void that forms at the base of the sill (from Fauconnier and Kersten 1982).*

Permeability in the caving zone is initially 40 to 80 times the permeability of the intact rockmass prior to mining (Singh, 1986). Booth and Spande (1992) noted permeability increases between one and several orders of magnitude, and Matthews and Wagener (1991) measured an increase of more than two orders of magnitude in Karoo sandstones and siltstones at Secunda.

The permeability increase is primarily experienced as an increase in vertical permeability (Fauconnier and Kersten, 1982). Vertical permeability is frequently almost negligible in Karoo rocks. Longwalling opens new, highly permeable pathways between lower and higher levels in the rockmass. This has significant consequences for the destination of rainfall recharge at such sites.

In the absence of mining-induced increases in vertical permeability, the deep aquifer is recharged via very widely-spaced natural fractures in the base of the shallow aquifer. Over high extraction areas, the permeability increase results in drainage of water from the shallow aquifer into the mine workings. Rainfall recharge of the shallow aquifer follows the same route. This may increase the proportion of rainfall that infiltrates to the mine by an order of magnitude.

This dilutes the brine placed in the mine workings beneath the zone of increased recharge, as indicated by the water quality results (Figure 2). It also develops flow paths over which post-mining hydraulic gradients can drive flow vertically (Figure 3). These may constitute starting points or end points for “u-tube” flow, that is, groundwater flow moving vertically down to the mine, potentially “driving” brine or deeper groundwater back up to shallower levels where there is a risk of decant. The impact of fluid density was not considered in the modelling and remains an area for future research.

Conclusions

Field evidence confirms that roof collapse ("goafing") over longwall mining area significantly increases the vertical permeability of the overlying Karoo fractured rock aquifers. Similar effects are not observed over bord-and-pillar workings.

Vertical hydraulic gradients that develop due to permeability changes over mined ground can induce "u-tube" flow. This can potentially drive brine and groundwater back to shallower levels where surface decant or access to contaminated groundwater is a risk.

High risk areas for brine storage are confined to the immediate vicinity of high extraction mining. Therefore, bord-and-pillar workings which maintain the integrity of overlying aquifers are preferred as potential brine storage areas.

Acknowledgements

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