ASSESSMENT OF HOW WATER QUALITY AND QUANTITY WILL BE AFFECTED BY MINING OF THE WATERBERG COAL RESERVES

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ABSTRACT

From local and international experience, it is known that coal mining has a pronounced impact on surface and groundwater quality and quantity. The influx of water may be as low as 1% of rainfall for deep border and pillar mines with no subsidence, to as much as 20% for some opencast mines (Hodgson *et al.* 2007). Such differences have significant impacts on the quantity and quality of surface and groundwater resources on the local scale and further afield. The Waterberg coal reserves represent the only large area with proven coal reserves remaining in South Africa. These reserves are targeted for large-scale mining in the foreseeable future. The application of lessons from other mining areas is appropriate here. The fact that new extraction options such as *in-situ* coal gasification are considered in addition to more traditional mining options, brings additional uncertainties to the fore. Although several factors, in addition to the effect on water resources, should be considered when selecting a mining method, the long-term effect on water quality calls for a careful consideration of alternatives. It is desirable that both developers and regulators be aware of the long-term liabilities and costs associated with different mining methods.

The Waterberg coal reserves are situated in a relatively dry area. In view of the low rainfall and limited surface water resources, the necessary level of safeguard measures to ensure the quantity and quality of existing water resources is unclear. Experience from other areas cannot necessarily be extrapolated directly. A scoping level study was performed to consolidate the existing information on the geohydrology and pre-mining water quantity and quality of water resources associated with the Waterberg coal reserves. New data regarding water quality and acid-base potential for the different geological areas (through field investigations) and geology and mining methods, were obtained.

1. STUDY AREA

The study area is located in the Limpopo province of South Africa, and is known as the Waterberg Coalfield. The Limpopo province is South Africa's northernmost province, situated within the great curve of the Limpopo River (see Figure 1). The study area extends from the town of Lephalale in the east to just west of the town Steenbokpan in the west, and up to the border, with Botswana in the north (see Figure 2). The study area covers an area of more than 2300 km^2. With regards to infrastructure there is at present one operational colliery and one operation power station with a second power station currently under construction, located in the study area.

The area has a low rainfall and is drained by two rivers, namely the Mokolo, running north-south, and the Limpopo, running roughly north-south/west. The Limpopo River is a perennial- and the Mokolo a non-perennial river.

The study area has a dry climate, receiving only summer rainfall. The average annual rainfall for the area varies between 285mm and 560mm (SA Weather Service, 2008).

Figure 1. Location of the study area in the Limpopo province.

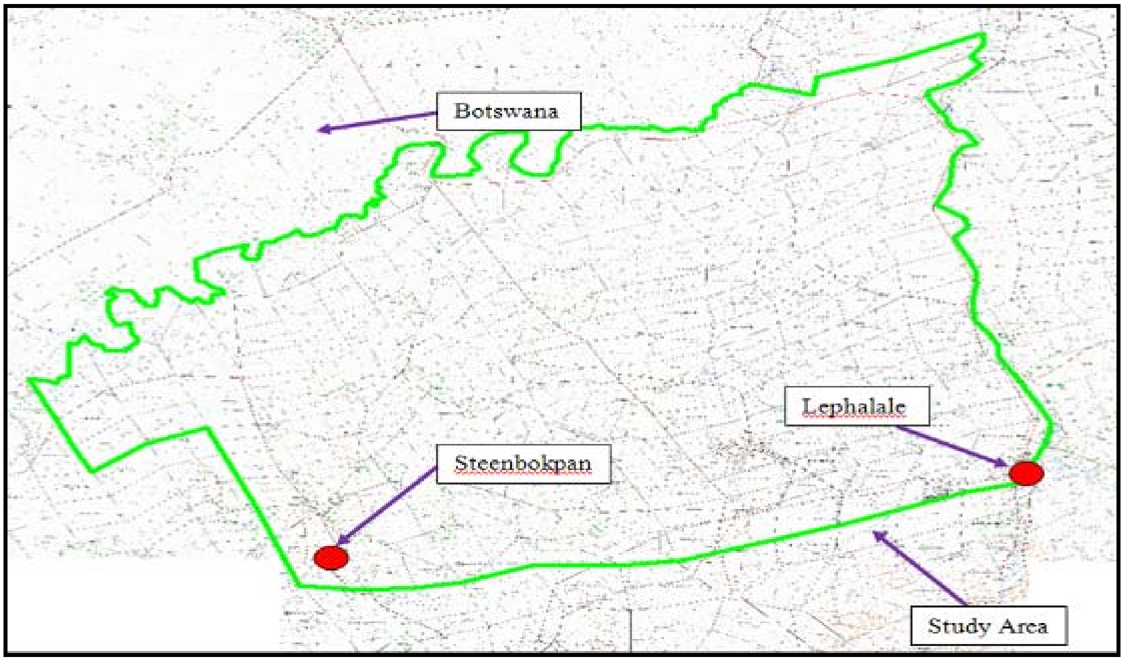


Figure 2. Location of the enlarged study area.

2. GEOLOGY & MINING

Coal was discovered on the farm Grootegeluk while drilling for water in 1920. Iscor began the development of the Grootegeluk colliery in the 1970s, with the mine producing its first 200 kt low-ash coking coal in 1980 (Snyman, 1998).

The Waterberg coalfield trends east–west, and is heavily faulted (see Figure 3). It is composed of sediments of the Karoo Sequence and forms a graben structure, bounded in the north by the Zoetfontein fault, and in the south by the Eenzaamheid fault. The Daarby fault subdivides the coalfield into the shallow opencastable western part and the deeper northeastern part of the coalfield (a displacement of some 400m).

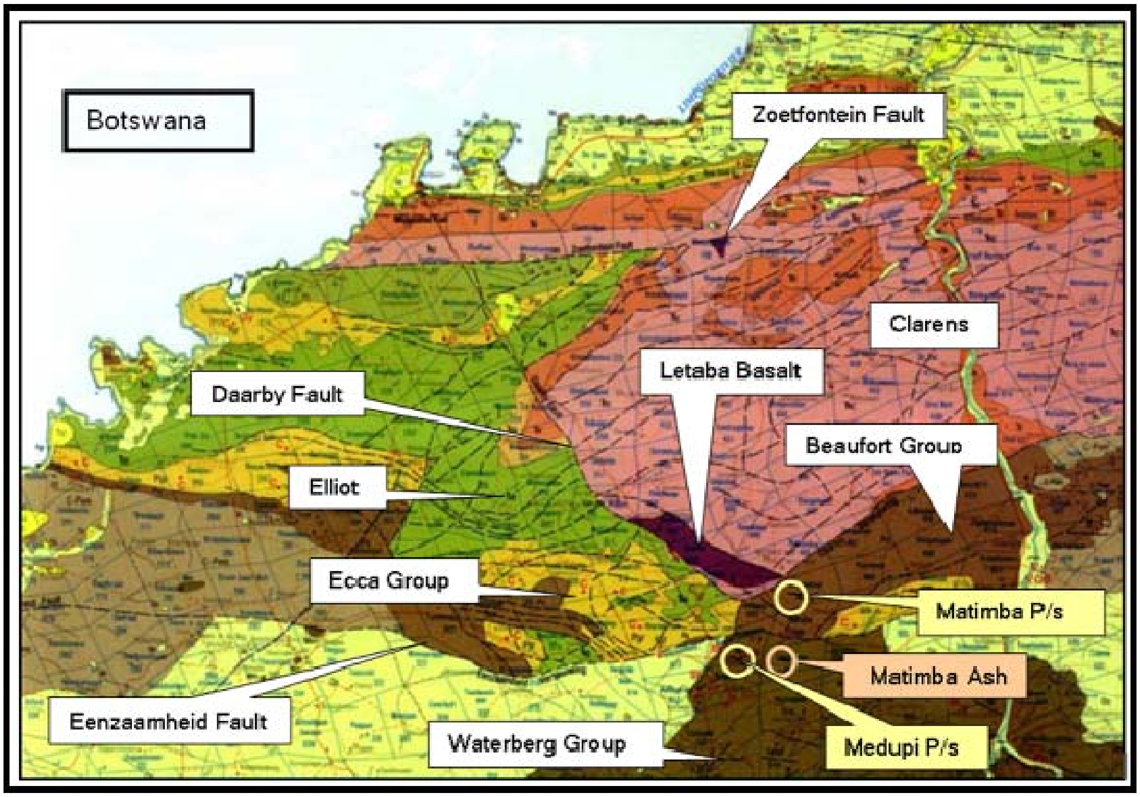


Figure 3. Simplified geological map of the Lephalale coalfield.
(Department of Mineral and Energy Affairs Geological map Series: Ellisras)

The Zoetfontein fault resulted from pre-/during-Karoo depositional tectonism, whilst the Eenzaamheid and Daarby faults resulted from post-Karoo depositional tectonism. All the units of the Karoo Sequence are present in the coalfield, and the subdivision of the Karoo Sequence is mainly based on lithological boundaries, consisting, from top to bottom, of the Stormberg Group (Letaba Formation), followed by the Beaufort Group, the Ecca Group and the Dwyka Group. Within the Waterberg coalfield, coal occurs in both the Vryheid and Grootegeluk formation, (which are equivalent to the Volksrust formation) of the Karoo Supergroup.

The coal-bearing interval is 115 m thick, and is subdivided into 11 zones. The lower four of these form part of the Vryheid formation (Snyman 1998). These zones also coincide with the four lower seams of predominantly dull coal, which have average thicknesses of 1.5 m – 5.5 m. Zones 5 to 11 occur in the Grootegeluk formation, which consist of rapidly alternating mudstone and thin coal seams. This coal mainly consists of bright coal.

According to Dreyer (2009), the deepest level to which a mine in the area can be economically opencasted in is the coal seam 2. Surface mining below this layer is considered uneconomical. It is possible to use subsurface methods for future coal mining in the future. The barrier between the opencastable and subsurface mineable coal is a thick succession of Ecca sandstone (Dreyer, 2008 / 2009). Cross-sections of the coal seam and groundwater level are presented in Figure 4. An exaggerated 3D view is provided in Figure 5.

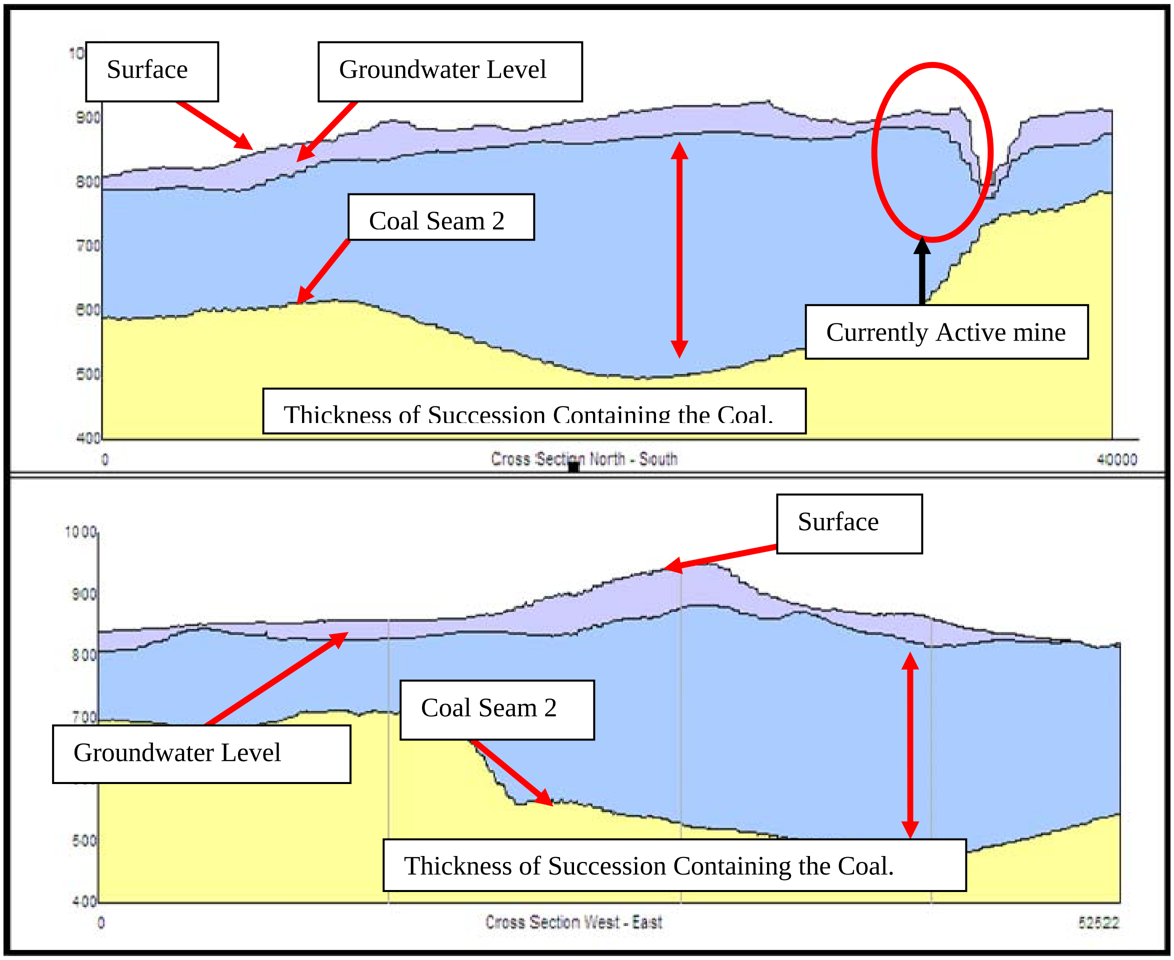


Figure 4. North/south (top) and west/east (bottom) cross-sections of the study area.

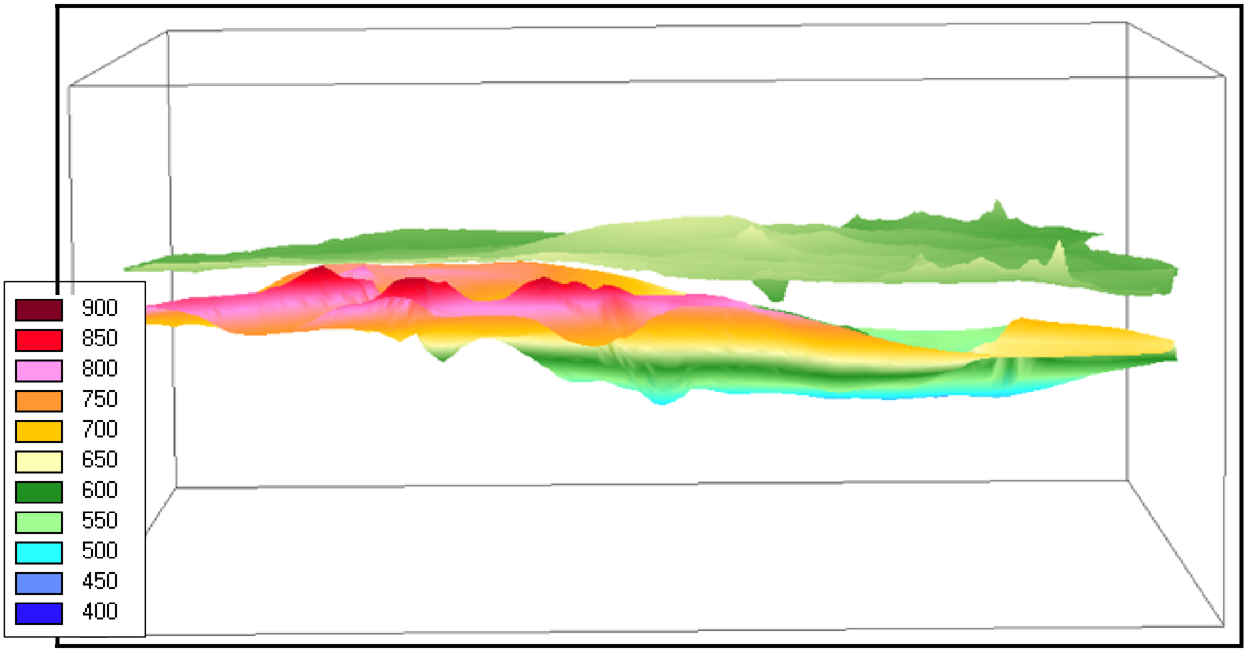


Figure 5. Exaggerated 3D side view of the topography and coal seam 2.

The study area can be divided into three main categories, according to the weathering of the geological strata. These are

- Areas that contain the full succession of geology
- Areas that have been weathered down to the middle Ecca and
- Areas that have been weathered down to the lower Ecca

3. GEOHYDROLOGY

There are two distinct and superimposed groundwater systems in the geological formations of the coalfields in South Africa, as described by Hodgson and Krantz (1998). These are the upper weathered aquifer and the system in the fractured rock below.

The Weathered Groundwater System

The top 5-15 m normally consists of soil and weathered rock. The upper aquifer is associated with the weathered horizon. Water may occur in boreholes at this horizon. These aquifers are recharged by rainfall.

The weathered zone is generally low-yielding, because of its insignificant thickness. The quality of the water is normally excellent and can be attributed to many years of dynamic groundwater flow through the weathered sediments. Leachable salts in this zone were washed from the system some time ago.

The Fractured Groundwater System

The grains in the fresh rock below the weathered zone are well cemented, and do not allow significant water flow. All groundwater movement therefore occurs along secondary structures such as fractures, cracks, joints or intrusions in the rock. These structures are best developed in sandstone and quartzite; hence the better water-yielding properties of the latter rock type.

Dolerite sills and dykes are generally impermeable to water movement, except in the weathered state. In terms of water quality, the fractured aquifer always contains higher salt loads than the upper weathered aquifer. The higher salt concentrations are attributed to a longer contact time between the water and rock.

4. WATER LEVELS IN THE STUDY AREA

Water level data are available for several of the boreholes in the study area (Figure 6). The average pre-mining water level is 28 m below the surface. At the extreme, the water levels range from artesian boreholes to as deep as 154 m below the surface.

The water levels in the study area vary greatly; the artesian boreholes predominantly occur near the Mokolo River, where the groundwater level and the surface topography intersect, while deeper water levels occur near the centre of the study area, due to a rise in elevation. Another reason for the increase in water level depth is the high levels of abstraction for watering livestock in certain areas.

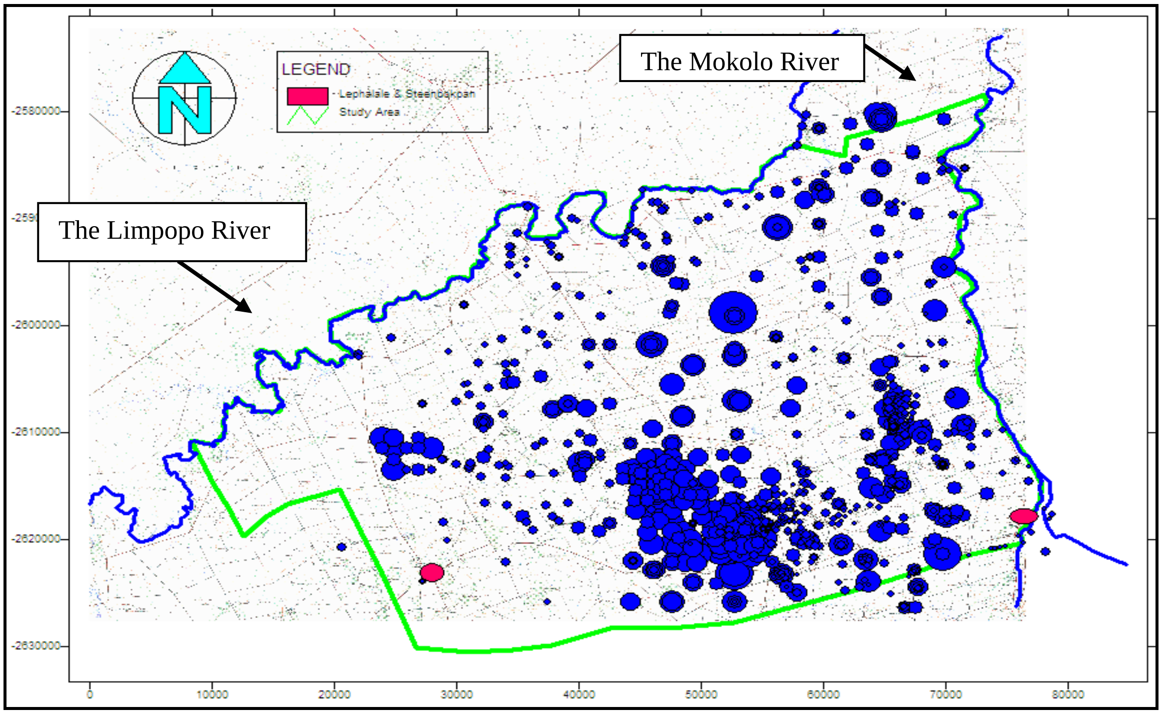


Figure 6. Map showing boreholes with proportional distribution of water level data.

Contour maps of the topography, groundwater levels and groundwater elevations indicate that the groundwater mirrors the topography. Contour maps indicate that the central areas of the study area are the driving force for groundwater flow (see Figure 7), flowing away from the central part of the study area towards the low -lying areas near the boundaries of the study area, namely the two rivers. It can therefore be assumed that the predominant flow directions of groundwater in the study area is towards the east, west, and north, away from the central elevated regions, with little if any flowing towards the south.

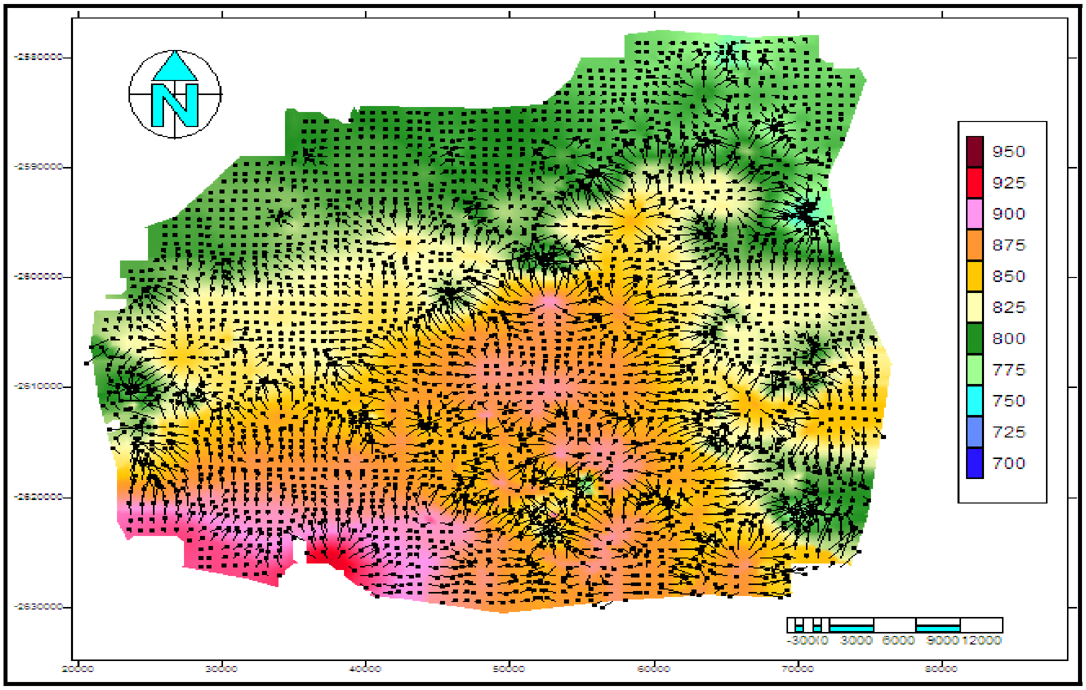


Figure 7. Map of water level elevations with flow directions.

Experience at the existing open-pit colliery suggests that the addition of new open pits to the area (specifically the central areas) will change the flow direction of groundwater. The topographical changes created in this way will have an impact on the water level and flow direction of the groundwater. The lower topography artificially created by the excavations will result in the groundwater flowing towards the mines. The degree to which this will impact the rest of the study area is currently unknown and will be determined by factors such as the depth, size and location of the pits. The groundwater flow towards the pits will continue until equilibrium between the influx of water and the water table is reached. The mine pits will therefore act as a sink for the inflow of water.

5. AQUIFER PARAMETERS

Slug tests and pumping test were conducted and analysed to determine and identify the trend or divergence from the expected norms for Karoo-type rocks. A total of 46 boreholes (Table 1) located throughout the study area have been pump tested and the results of the tests were analysed by means of the FC software programme developed by the Institute for Groundwater Studies at the University of the Free State. More boreholes around the currently active mine were tested than in any other location in the study area. Some tests were conducted to the west and some to the east. Those to the east were drilled by Department of Water Affairs and Forestry and are located in the Waterberg group. The north-eastern parts of the study area have not been tested, as this area is not to be mined.

Table 1: Results for the boreholes tested.

Site Name	T(D) m2/day	Yield L/d	Site Name	T(D) m2/day	Yield L/d
OBS2	4.4	5000	WBR15	19.64	7200
WB33	26.64	168000	WBR16	8.95	2880
WB35	8.78	160000	WBR17	507.85	12000
WB36	35	62068	WBR18	1.53	1200
WBR1	93.52	10800	WBR19	0.31	960
WBR2	10.02	7200	WBR20	0.93	2400
WBR3	10.62	8400	WBR21	0.36	1200
WBR4	9.16	4200	WBR22	1.19	2040
WBR5	5.53	3600	WB24	0.35	3785
WBR6	30.07	7200	WB27	124.06	44400
WBR7	1.12	960	WBR28	0.18	19047
WBR8	0.57	1200	SSpmt1	600	22860
WBR9	5.45	1000	SSpmt2	3	684
WB19B	15.5	11356	SSpmt4	15	2592
WBR10	1.3	4800	H21-0637	206.3	47844
WBR13	0.19	1200	H21-0638	143.2	56412
WBR14	10.75	36000	H21-0663	141.5	72720

6. RESULTS

According to the pumping tests conducted in the study area, there are vast differences in the transmissivities of the area. The pump test results indicated that the transmissivities and yields of the boreholes in the study area vary greatly, with transmissivities generally being low (as low as 0.31 m^2/d). Values as high as 600 m^2/d were obtained near the fault zones. From the findings it is evident that, depending on the location of the mines, it is possible that they may experience high levels (if they intersect the faults) or very low levels of groundwater influx. However, the area has a very low average transmissivity, which results in the slow movement of water and the slow influx of groundwater to most mines; 30000 m^3 per month of influx is for example found at the currently active mine (Dreyer 2008/2009). These findings conform to typical Karoo aquifer parameters.

7. RECHARGE

The recharge for the study area was calculated by means of the Chloride method (van Tonder and Xu, 2001). This method was chosen due to the availability of data.

Where: **% recharge =100* Cl(rain) / Cl(groundwater)**

The recharge was calculated for each individual borehole, and the harmonic mean (62.76 mg/l) for the chloride values was obtained (**Error! Reference source not found.**).

From the calculations, the recharge of the study area was determined to be 1.59% of the annual rainfall. This is in accordance with typical Karoo aquifers, and with maps for the study area produced by Vegter (1995), which indicated a recharge between 1.5% - 1.9%. From the data, a contour map was drawn (see Figure 8).

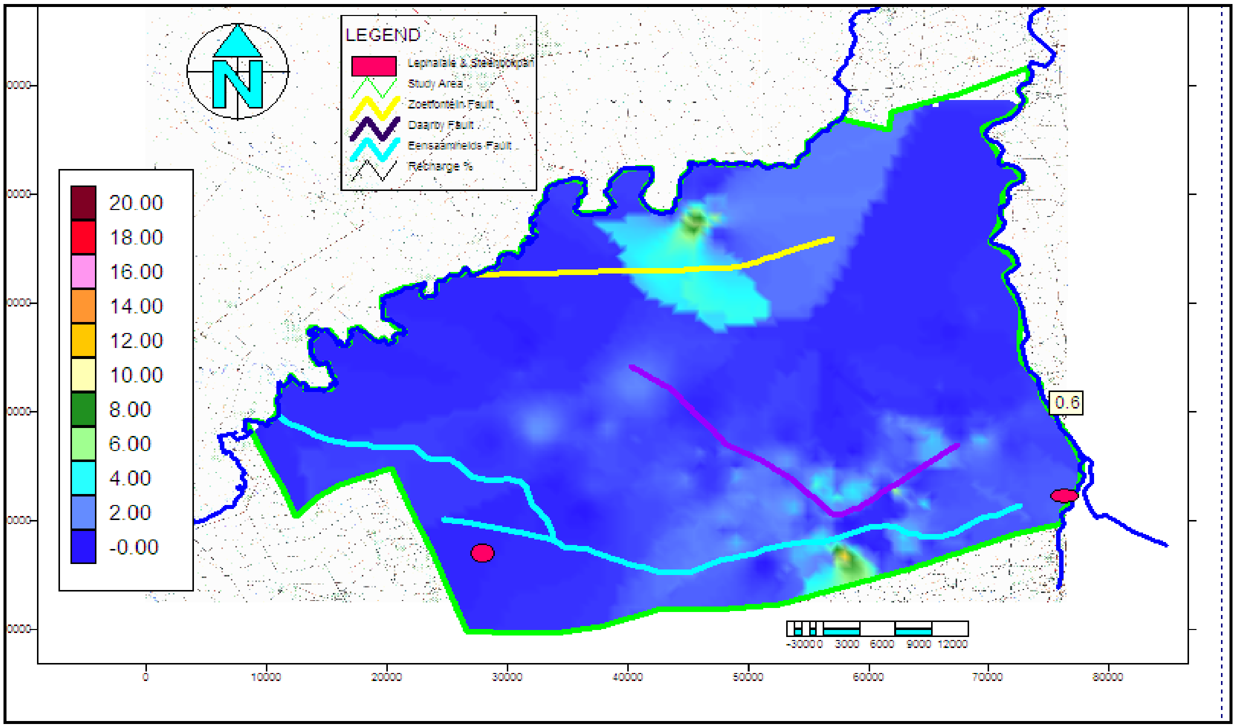


Figure 8. Recharge map of the study area (% recharge).

Figure 8 indicates that there are areas with high and low recharge to be found in the study area. The map further illustrates that there is an association between the faults and the degree of recharge, the areas with higher recharge being, in general, located near or between faults.

8. CHEMISTRY

Groundwater samples from across the study area were taken for chemical analyses. The samples were analysed for all macro-elements and a wide range of trace elements.

The analyses indicated that the groundwater in the study area have near neutral pH-values ranging from 6 – 8. The water does however have high TDS values, ranging between 600 and 2500 mg/L.

It was observed in the field that groundwater is not used for irrigation, due to the high salt content, and that filters are needed to remove the salts from water for domestic use. High Cl values are found in the water along with high levels of Mg, K, Na and SO_4. The SO_4 is predominant in areas with shallow coal-bearing layers or in cases where the boreholes were drilled into the coal.

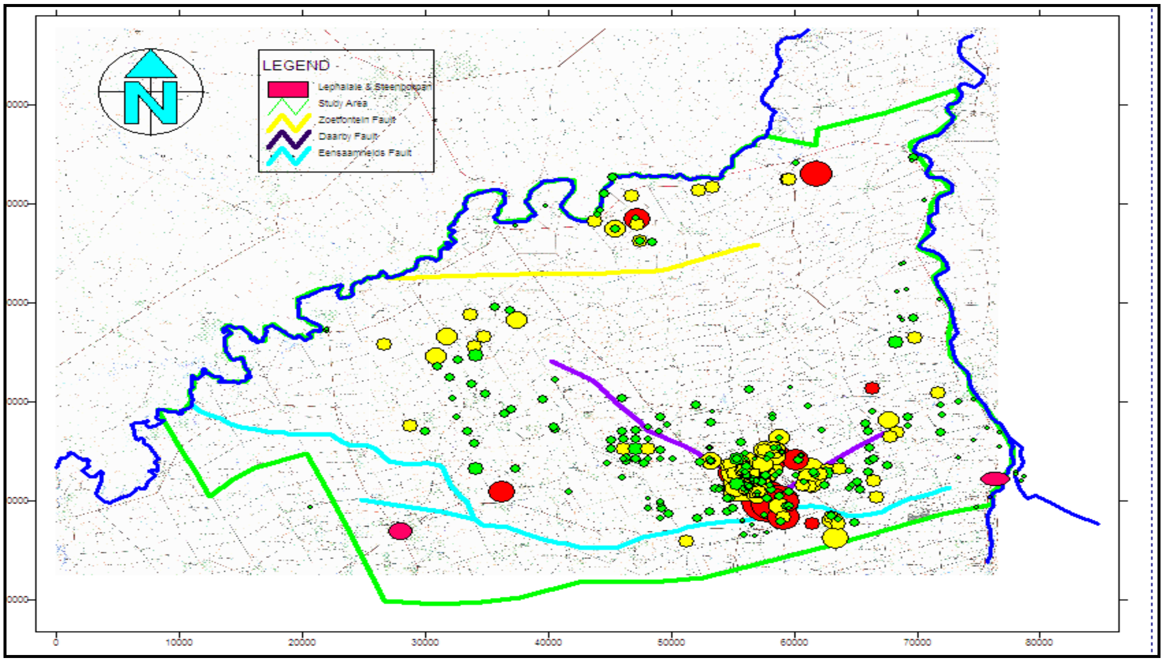


Figure 9. A map of the EC distribution found in the study area.

No clear correlation could be drawn with regards to high EC values and the location of structures in the study area, with the exception of some boreholes located between the Eensaamheids fault and the Daarby fault which had high Cl values indicative of very little flow in that area.

9. ABA ANALYSES

Geological samples were collected for ABA testing from various locations in the study area. The goal of testing was to determine any predisposition for acid generation in the geological layers, and whether there is sufficient neutralizing potential in the rocks to counter act the acid. The peroxide static test was used to analyse the samples. Samples were collected from the north/western parts of the study area, as well as from the south/eastern parts, as these areas are most likely to be mined. The results are as follows:

North/western Areas

Samples were collected from a core sample spanning 200 m. Some of the samples indicated a high risk of acid generation, with the final pH values of these samples turning acidic upon complete oxidation, while others indicate a lower risk.

The static tests on these core samples indicate that acid mine drainage will be produced upon oxidation in some of the samples, although there is also some buffering potential in some of the other samples.

South/eastern Areas

Samples were collected ranging from core samples to chip samples. Some of these samples indicate a high risk of acid generation, with their final pH values turning acidic upon complete oxidation, and others indicating a lower risk. From the static tests on these samples, it is clear that acid mine drainage will be produced upon oxidation; although the samples do contain buffer potential; care should be taken when re-depositing the spoils in the pit.

A set of sandstone samples was collected from beneath the second coal seam. This sandstone indicates the lowest level to which opencast mining in the study area will take place. The ABA analyses of these samples indicated that some acid will be generated for any given mass of the sandstone.

Discard

The test conducted on the discard indicated that they will generate acid upon oxidation. It is recommended that care should be taken when dealing with the spoil and that the method currently used at the Grootegeluk mine, in terms of replacing rock into the pit in the same succession as it was removed, should be maintained. This will lead to the least acid being generated.

10. MODELLING

Numerical modelling was done by means of the Processing Modflow for Windows (PMWin) software program, in order to determine if the mines would in the future reach a level at which they would decant. Three different scenarios were modelled, simulating different possible conditions present in the study area.

The scenarios modelled are as follows:

- A single pit (dewatering and decant) modelled at 3 different transmissivities (0.4 m^3/d, 0.28 m^3/d and 0.12 m^3/d).
- A single pit with a fault running through the pit from north to south (dewatering and decanting).
- The final scenario saw three pits having been mined with two major faults found in the study area (dewatering and decanting) being active as high transmissivity zones.

Modelling Results:

Inflow of Water:

- Scenario 1: The inflow varies between 748.82m^3/d and 754.72m^3/d for layers one and four respectively.

- Scenario 2: The inflow is predicted to be in the order of between 1751.51m^3/d and 1870.52M^3/d for layers one and four respectively.

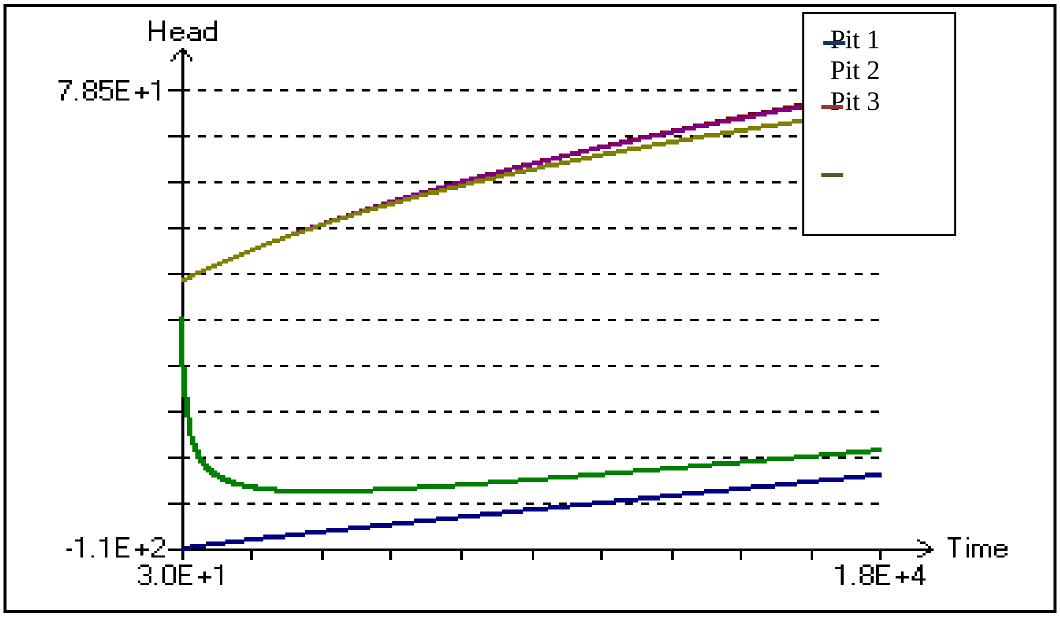
- Scenario 3: For layer four of the northern pit located the furthest away for a fault the expected influx is 754.72m^3/d while the expected influx into the south eastern pit is calculated to be 1282.58m^3/ in the same layer over 10 years.

Drawdown Cones:

- Scenario 1: A drawdown cone of was observed 2.8 km after 10 years.

- Scenario 2: The extent of the cone varies due to the influence of the fault, generally being 3.2km after 50 years.

- Scenario 3: The influence of the different pits and faults can clearly be seen with the drawdown cones varying between 3.2 km to 5.2 km after 50 years



The Head-Time graph for the third scenario.

11. CONCLUSIONS

It is predicted that the mining in the area will have a great impact on the groundwater and that careful monitoring is needed to ensure that a balance is maintained. From the chemical analyses and the ABA analyses, it is clear that the rocks in the study area are prone to acid generation, but that there is also potential for buffering.

Importantly, the low transmissivities of the formations indicate that it is highly unlikely that the open pit mines planned for the study area will ever create problems in terms of large volumes of inflow from groundwater.

This is due to the low rainfall and subsequently low recharge and high evapotranspiration in the area. It is therefore predicted that the pits will fill up with water until such a time as the current water level has been reached. When the pits are back-filled, the water level may rise above the initial water level, but will never reach a point where the water will decant from the pits.

12. REFERENCES

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13. ACKNOWLEDGEMENTS

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